"Queen-Gil"®

Á R P Á D   T Ó T H

Drip irrigation by Queen Gil Tape

Á r p á d   T ó t h

Drip irrigation by Queen Gil tape

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Introduction

Nowadays the drip irrigation systems are widely used.

There are several reasons for this. Firstly the meteorological factors, the amount of rainfall in the growing season is not enough and even that much is not evenly spread. Secondly, when we use the irrigation for distributing the nutrients, we can increase the amount of crops and keep the quality. And thirdly the price of the Queen Gil irrigation system does not follow the general trend of price increase, the rate here is much slower. With the application of cheaper production tools the profit can be increased, therefore the farmer has to consider the profitability of the investment. The increase of other production costs also accounts for increased use of the drip irrigation by Queen Gil tape because the use of any other more expensive type of technology in a drier growing season could not provide sufficient economical result.

Today the drip irrigation by Queen Gil tape is a part of advanced technology. We have to forget about the idea of using irrigation technology for saving the products but we have to include irrigation and nutrient solution in the technology so it makes maximum profitability possible.

The aim of this book is to introduce the international results of watering, nutrient solutions and related areas for farmers and growers, to benefit all the characteristics of the Queen Gil irrigation system, to make cheap investment possible and to avoid the complications of operation. Data tables and related quality categories and examples of calculation make easier understanding possible.

dr. Árpád Tóth

1. Irrigation and the soil

The goal of agricultural production is to receive crop yield without decreasing soil productivity or causing changes of the soil, which are difficult and expensive to maintain. Productivity is the most important attribute of soil, which allows water, air and plant nutrients to co-occur. By integrating several natural resources the soil provides living space for the activity of microorganisms and acts as arable land for plants. The agricultural land is the most important reviving natural resource. The growers should consider rational usage, protecting and increasing productivity as their primary task.

During planning and creating the Queen Gil irrigation plant we have to consider the chemical water characteristics and their effect on soil characteristics, vegetation and irrigation plant establishments during the years of operation.

1.1. Effects of irrigation

Favourable effects influence the soil water budget, which in turn affect the vegetation.

a. *Water supply.* Continuous water input into the active root zone prevents the loss of crop quantity and deterioration of quality. By daily evaporation we can avoid atmospheric drought formation within the vegetation.

b. *Improving nutrient budget.* With continuous water input the biological activity of the soil remains at the same level during the growing season. Therefore most of the nutrients become free, so the available nutrient source increases. This is very favourable, because the nutrient uptake of the plants increases when water supply is sufficient.

c. *Improving soil structure.* Continuous biological life increases the mass of root system, the production of the valuable humus. The organic substances of decomposing roots and the originating humus layers help to create positive structure change.

Unfavourable effects can become significant and in several cases even higher than favourable ones, so a decrease in soil productivity can occur. Importance of unfavourable effects is further increased because the improvements of irrigation can be already experienced during the first growing year, while unfavourable effects can take several years to occur. The unfavourable characteristic can prevent crop production for several years or forever. The improvement of the soil can get very costly, deep-ploughing, liming or larger amount of organic fertilizer spreading become necessary.

a. The process that result in the accumulation of different salts in the soil is referred to as *soil salinization*. Increase in salt content can occur if the sodium and total salt content of irrigation water is not adequate for the actual soil type and leaching does not carry away all the salt input. Soil salinization can also occur when draining irrigation water makes ground water level high so its high salt content accumulates near the surface. Accumulation of sodium salts, named alkalinization, has a bad influence mainly on the physical characteristics of the soil (difficult to cultivate, coarse surface, low water absorption capacity and low level of available water). Increase of salt concentration, named salinization, reduces the number of productive plants the emerging seedlings and young plants are especially sensitive to high salt content.

By removing polythene foil of the greenhouses for winter season we can help to flush the salt content, accumulated within and below the cultivated area.

Supplying water into the soil by irrigation we can prevent the rise of saline ground water, thereby the damage of vegetation.

b. *Leaching of nutrients.* Supplying larger amount of irrigation water, the wet zone contacts the soil capillary zone so some of the nutrients are released to the soil solution. Nutrients can be also lost when they are leached by irrigation water so deep that the plant roots are not able to utilize them. This process is very common in the case of nitrogen, which tends to form a solution with water. Its leaching is partly a financial loss but on the other hand water becomes unsuitable for drinking. Therefore we have to determine the amount of irrigation water so that no leaching occurs or we should input nitrogen during the growing season according to plant utilization. In intensive cultivation the best solution can be daily nitrogen output by the Queen Gil drip irrigation system, according to vegetation demands.

c. The secondary effect of irrigation is the *compaction* of the soil. Rain saturates irrigated soils sooner, thus their load-bearing capacity decreases. In addition the crop production is much higher than of the non-irrigated areas, so harvesting and transportation requires increased machinery use. Because of the compacting effect we should apply cultivation in different depths in order to prevent the formation of the "plow pan" layer. That layer has low water permeability and prevents root penetration towards deeper layers.

In every four season the inclusion of crop species with short growing season provides a possibility for deep soil tillage.

d. The *sealing* and crusting of soil surface is formed in spots by the cumulated effect of physical and chemical processes in the orchards where drip irrigation tube is installed above the ground surface. The main physical damaging effect is when the water drops hit bare soil. The amount of energy affecting the surface depends on the number, size, speed of the drops and the angle of impaction.

Chemical processes also play important role in the sealing process. The ion composition and their relative quantity in the irrigation water differs significantly from the composition of soil solution. The stability of clay aggregate structures is influenced by the quantity and ratio of the different ions. Adding large amount of water with low ion content drains structure-stabilizing ions from the top few millimetres of the soil thus the aggregates fall apart into significantly smaller particles. At the same time diameter and quantity of the pores also decreases, which is further decreased by the impact and compacting effect of water drops. The result of this process is the serious decrease of water infiltration and the development into a hard surface crust on drying. Formation of a 2-3 mm thick layer is already enough for the serious decrease of water drainage.

e. *Soil erosion* occurs even on flat surfaces because there are always some micro-differences of the terrain. Higher application water than the soil hydraulic conductivity or high rainfall intensity can produce water runoff, which facilitates the carrying away of soil particles to different extents. Factors influencing the extent of erosion are the intensity and duration of irrigation water or rainfall, the mechanical composition, humus content, structure of the soil; the length and steepness of slope; type of the crop grown, land cover, crop rotation and cultivation. Soil erosion is marked by the shiny crust deposit in depressions of the surface, which cracks and curls on drying because the crust contains dissolved humus matter, which is the easiest for the water to carry. The use of row cultivator decreases erosion because the surface becomes rough and the created micro-channels prevent water runoff.

1.2. Factors affecting the soil water budget

The soil texture

The mechanical composition or soil texture describes the size of the soil particles. Scientists group these particles into soil separates according to their equivalent diameter. The most common is the Atterberg classification system, which describes the following categories.

Particles > 2 mm are called *gravel*s, which are not considered useful for soil texture.
Particles of 2-0.2 mm permeate water very easy but can hold little water. This fraction is the *coarse sand*.
The particle size of 0.2-0.02 mm is called *fine sand*, which permeates water easily and can absorb already 50 mm of water in a 1 m deep layer.
Particles of 0.02-0.002 mm are classified as *silt*, which has low water permeability but high water absorption capacity and the adsorption of ions is possible to some extent.
Particles <0.002 mm in diameter are classified as *clay* and have a very restricted or lacking water permeability but show high water and ion adsorption capacity.

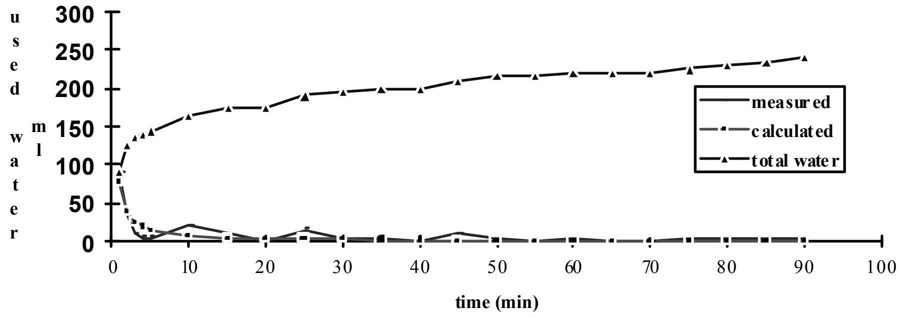
Physical classification of the soils is normally determined according to other physical characteristics than mechanical structure of the soil. Such characteristics are soil matric potential, hygroscopic coefficient, elutriation rate and the 5-hour capillary lift.

The retentive capacity and water infiltration of soils

The retentive capacity of soils determines the capability of the soil to infiltrate water when flooded without filling all soil pores with water. After saturating all the pores the water movement per unit of time decreases and water permeability will be stabilized. Water permeability mainly depends on the amount of pores, more specifically on the ratio of different pore diameters, characteristics of soil particles, concentration of penetrating water and on the ratio of different ions. The soil containing lots of montmorillonite clay minerals is more sensitive to the quality of the irrigation water than those containing illite and kaolinite. When the salt content of water is lower than EC (Electrical Conductivity) = 0.2 mS/cm (about 130 mg/l) the water permeability drastically decreases. Because the concentration of rainfall is about 0, we can improve infiltration by using high concentration water for irrigation during rainfall. When the salt content is higher, higher SAR value is possible without changing the level of permeability. Figure 1. shows the dynamics of water infiltration under field conditions.

Figure 1.

Calculated and measured infiltration and the total amount of water use on a clay loam soil, Kenderes field No.4, 08. month



Bulk density, porosity and water content

The bulk density of the soil includes the mass (weight) of the solid (ϕ_S), liquid (ϕ_l) and gas fraction (ϕ_g) of the soil. We normally do not take into account the gas fraction during calculations, because its weight in 1 m^3 of soil (0.13-0.65 kg) is negligible. In case we calculate the joint weight of solid and liquid particles in a standard volume, we receive the *wet bulk density* of the soil. In case we divide the weight of solid particles by the volume then the result is the *dry bulk density* (Ts). For the calculations the density of the solid fraction is considered 2650 kg/m^3 and the density of the liquid component is 1000 kg/m^3. When the type of the bulk density is not specified, it always means the dry bulk density. The *particle density* of the soil (ρ) is calculated from the mass (weight) of the solid particles. The average particle density of the minerals is calculated to equal with 2700 kg/m^3, that of organic materials to be 1400 kg/m^3. Their rate in the soils results in the soil particle density of 2650 kg/m^3, this value is used in field calculations.

The size of pore space or total pore space can be calculated from data on bulk and particle densities. Ts/ρ ratio means the total volume of solid particles. If this value is subtracted from the total soil volume, the result gives the ratio of pores. Multiple it by 100, we get the percent pore (P)%.

$$P\% = \frac{\rho - T_S}{\rho} \times 100.$$

The percent pore space has a great influence on the water conductivity and retention of soils. To be more precise, we have to know the size of the different pores, the *differential porosity.*

Name	Diameter (μm)
macropores	> 100
medium pores	30 - 100
micropores	< 30

Although there is no clear-cut demarcation, the different size classes can play the following roles. The macropores allow movement of water when flooded (2 phase soil) but do not retain that, provide good aeration and high water conductibility. Medium size pores also play part in water movements (3 phase soil), in the different potential equalization processes and together with the micropores they hold water in the soil for uptake by roots.

For the measurement of the soil water content in the field normally 3 repetitive samples are taken from different layers of the soil with a cylinder of 100 cm^3. The samples are closed hermetically immediately then their weight is measured. After drying, the mass is measured again. The *mass water content %* (Θ_t) can be defined using data of the two measurements and shows the mass of water associated with 100 g of soil.

$$\Theta_t = \frac{mass\ of\ water(g)}{soil\ dry\ weight(g)} \times 100$$

Dividing the measured soil dry weight by the volume gives the *bulk density* (Ts).

Multiplying the mass water content % by the bulk density gives the *volumetric water content %* (Θ). Θ % shows the volume of water (ml) associated with 100 cm^3 of soil.

$$\Theta = \Theta_t \text{ x Ts}$$

Soil water content can be also expressed *in mm*, which indicates the quantity (mm) of rainfall equivalent to the moisture content of a certain soil layer. This can be calculated from the water content of Θ, because 1% of volumetric water content = 1 mm water content of a 10 cm thick layer. For calculating water reserves of thicker layers we should simply sum the water content of the 10 cm thick portions.

From the water content in mm the *water reserve of soils in m^3/ha* can be easily calculated since 1 mm water content = 1 litre water covering a surface of 1 m^2, therefore

1 mm = 10000 litre water of 1 ha, which equals 10 m^3.

Example: the weight of the soil in the measuring cylinder before drying is 172 g. Soil dry weight is 132 g. This means that the soil contained 172-132=40 g water. The mass water content is Θ_t= (40/132)x100= 30.3 %.

The volume of the cylinder is 100 cm^3, therefore the bulk density is (Ts)= 132 g/100 cm^3= 1.32 g/cm^3. The volumetric water content is (Θ)= 30.3 x 1.32= 40 %. The water content of a 20 cm thick soil layer is = 40 x 2= 80 mm water. Therefore the water content of a 20 cm thick soil layer on 1 ha is 800 m^3.

Water forms in soils

Depending on the binding energy of the soil, different water budget types (Table 1.) can be separated. Water capacity indicates the water retained by the soil under different conditions. The *field capacity* (VK_{SZ}) indicates the water amount, what the soil can hold, retain against gravity under natural conditions. The average measured laboratory value of the matric potential is 0.3 bar. For its measurement we should push a metal frame of 50 x 50 cm into the soil and fill it by 100 mm water. After the infiltration of the water, cover the soil surface with plastic sheet preventing evaporation. After 1-2 days on sandy soils and after 3-5 days on clay soils we can take samples till the level of water penetration for measuring the field capacity.

The soil water content when the plants are in a permanently wilted condition (wilting point) is called the *wilting coefficient* (HV). Average measured value is 15 bar, actual value depends on the type of the plant, the suction force of the roots. When water content gets near to this value, the plants are not yet dead but amount of yield decreases significantly.

Total available soil water (DV) is the amount of water available for plants, VK_{sz}-HV.

Example: The texture of the soil is loam and VK_{sz}= 30 mm/10 cm, HV=15 mm/10 cm, therefore DV=30-15= 15 mm of water in the 10 cm thick layer. The cultivated layer is 40 cm deep, the total available water is 4 x 15 mm/10 cm thick layer = 60 mm.

Table 1.

Water budget characteristics of different soil textures

Soil texture	Field capacity	Wilting coefficient	Available soil water
	mm/10 cm thick layer		
Sand	< 15	< 5	5-10
Sandy loam	15-25	5-10	10-15
Loam	25-35	10-20	15-22
Clay loam	35-42	20-27	12-17
Clay	42-50	27-35	10-15

The value of wilting point – measured by a 15 bar suction force – can be determined as the average of the wilting coefficients of different plant species. This point cannot be considered as the minimum soil water content because the decrease of yield has already started. The amount of water required for the stable growth of the different plant species, the plant-available soil water is about 40-80 % of DV. This is mainly species and variety dependent, in general plants producing large green surface (vegetative type) require higher water content than plants with deep root system. The value is about average 50 % in arable land. By increasing air temperature, decreasing moisture content the need of plants for water uptake increases. For calculating the water need of different plant species the multiplying factor (p, fraction of available soil water) can be found in Table 6. Continuing the example above, if the product is sweet paprika, we should start the irrigation when DV x p = 60 x 0.25 = 15 mm water has been absorbed from the soil.

1.3. Water quality influence on salinity

Irrigation waters always carry significant quantities of soluble salts. The level of salinity depends on the origin of the water. The soil solution or ground waters contain more than the lakes or reservoirs. The lowest salt content can be found in the river waters, irrigation pipes.

The quality of irrigation waters is defined by the following characteristics.

1. Total soluble salt content, expressed in mg/l. The total soluble salt content of good quality irrigation water should not exceed 500 mg/l. On light, sandy soils, where ground water can be found in deeper layers only, higher salt content of about 800/1000 mg/l still means good quality. The reason for this is partly the low clay content of the soil, which provides relatively good water conductivity even for waters of higher concentration and adsorbs less soluble salts, which can be leached into deeper layers during winter rainfall. On the other hand the ground water of deeper layers (3-4 m) does not affect the distribution of salt content in surface layers. Water quality and irrigation should be evaluated with full knowledge of the actual soil and vegetation requirements.
   The soluble salt content of irrigation water can be calculated from the electrical conductivity (EC) of the water the following way: mS/cm or dS/m x 640= x ppm, or mg/l salt content. Scientific literature gives different values for allowable total salt content or electrical conductivity.

2. The relative concentration of sodium ions (Na) compared to the concentration of all cations, expressed in % /Na %/.

$$Na\% = \frac{Na^{+}}{Ca^{2+} + Mg^{2+} + K^{+} + Na^{+}} \times 100 \qquad \text{mgeq/l}$$

The less sodium ion the irrigation water contains, the better its cation composition will be. Regarding the salinization not only is the absolute Na^{+} content important but also its relation to other metal ions. This relation depends on the dispersion of clay minerals. The level of dispersion depends on the type of the clay minerals, the concentration of the solution and the ratio of the ions.

The tolerable amount of Na% depends on the anion composition of water and on soil characteristics of the field to be irrigated (ratio of the different clay mineral types). Experiments proved that there is less Na adsorbed from a sodium-chloride or sodium-sulphate solution than from a sodium-carbonate solution of the same Na^{+} content. Thereby the Na% of hydrocarbonate water can be maximum 35, while 45% is still acceptable for the water containing considerable amount of chloride or sulphate but less hydrocarbonate.

3. Relative concentration of magnesium (Mg) ions compared to the total amount of Ca+Mg in soil solutions, expressed in %.

$$Mg\% = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100 \qquad \text{mgeq/l}$$

From the irrigation water containing lots of magnesium the soil colloids can adsorb considerable amount, replacing the calcium (Ca) thereby decreasing the water conductivity, structure of the soil. When the Mg% reaches 40-50%, we should question the applicability of irrigation on strong, clayey soil.

4. The sodium adsorption ratio, SAR value, together with the salt content (Table 2.) evaluates the change of ground water conductivity due to irrigation water.

Table 2.

The expected affect of SAR and the water salt content on the water conductivity of the soil (Ayers & Westcot, 1989)

SAR value	Expected change in soil characteristics low	moderate	high
	Electric conductivity (dS/m)		
< 3	> 0.7	0.7-0.2	< 0.2
3-6	> 1.2	1.2-0.3	< 0.3
6-12	> 1.9	1.9-0.5	< 0.5
12-20	> 2.9	2.9-1.3	< 1.3
20-40	> 5.0	5.0-2.9	< 2.9

For reclamating the physical and chemical characteristics of the soil we can use large amount of (> 60 t/ha) organic fertilizer or liming materials. The aim is to reach approximately neutral pH and reach maximum calcium adsorption. To calculate the lime content we should consider the Na content, the thickness of soil layer to be reclamated, the bulk density of the soil and the size of the land.

The pH value describes the chemical reaction of the soil. When evaluating pH value of soils the following facts should be considered.

- The pH value depends on the soil : solution ratio, therefore only results of the same examination method can be compared. Normally we use 1:2 soil : solution ratio but sometimes ratio of 1:5 or saturated extraction is used for analysis. Measuring the chemical reaction of the suspension or of the filtered solution also gives different results.
- The soil pH is defined in water or potassium-chloride (KCl) suspensions and these two values differ considerably (0.5-2 pH) from each other. Results of foreign studies sometimes analyse $CaCl_2$ solution, which gives a third value.
- In general, laboratory analysis of the soil suspension chemical reaction depends on the pH value of the studied soil sample, but the result is not the same.
- Natural soils show a seasonal change of pH value.

1.4. Effect and treatment of irrigation water

1.4.1. Water qualification by clogging resistance

The Queen Gil drip irrigation system has different water quality requirements because the diameter of the emitters is so small that the system needs strict regulations. It is difficult to set the limits and criteria because evaluating the joint effect of the biological, chemical and physical components of different composition and proportion (Table 3) on clogging the system outlets can be a very complex task.

Components of water can be classified as follows:

- suspended organic and inorganic materials,
- dissolved solids,
- live biological bodies, like algae and mucous bacteria. These bacteria cannot be filtered, suspended solid particles get stuck and accumulate on the sticky colonies. They also assist in the enzymatic transformations of soluble elements (iron, manganese, sulphur) and this process can result in the accumulation of insoluble particles.

It is difficult to quantitatively define the applicability of waters from different sources for irrigation. Only criteria of maximum values can be set. Evaluation of physical particles is easier but biological and chemical elements are more complex especially when fertilizers, chemicals are added. Table 3. introduces the internationally used water quality table, which contains the value of the most important characteristics. When we find that the data of water samples indicate moderate or severe tendency for getting clogged, chemical treatment of water is definitely required.

To evaluate the saturation of the salts the Langelier Saturation Index (LSI) can be used. For more accurate determination of the index, samples are brought to the laboratory and index values are given for analysis. This value also helps to define required quantity of acid to be used for water treatment.

Table 3.

Water qualification for estimating the tendency of drip irrigation elements to become clogged (Nakayama, 1982)

Cause of clogging	Clogging hazard		
	slight	moderate	severe
Physical			
Suspended solids (mg/l)	<50	50-100	>100
Chemical			
pH	<7.0	7.0-8.0	>8
Dissolved solids (mg/l)	<500	500-2 000	>2 000
Manganese (mg/l)	<0.1	0.1-1.5	>1.5
Iron (mg/l)	<0.1	0.1-1.5	>1.5
Hydrogen-sulphide (mg/l)	<0.5	0.5-2	>2.0
Biological			
Bacterial population (no./ml)	<10 000	10 000-50 000	>50 000

The following measurements have to be completed for analysing water quality

1. Total amount of suspended particles. It is measured after filtering the water by drying the particles retained by the filter on 105 °C.
2. Amount of organic suspended materials. It is measured by heating the full amount of suspended materials on 600 °C.
3. Total amount of dissolved solids, measured by distillation of the filtered sample.
4. Measurement of the chemical reaction (pH).
5. *Total water hardness*: caused by base-forming cations, mainly calcium- and magnesium ions. Carbonates and hydrogen-carbonates of the water give the *variable hardness*.
6. Hydrogen sulphide content.
7. Iron and manganese content.
8. Biological life, number and species of individuals.

1.4.2. Water quality effect on plants

Evaluation of water quality should always be based on laboratory analysis. This is especially important when growing plants without soil, where all the nutrients are added in solution. For determining the quantity of nutrients needed, we have to know the amount to be found under natural conditions.

We always have to measure the quantity of Ca^{2+}, Mg^{2+}, Na^{+}, NH_4^{+}, K^{+} cations and Cl^{-}, SO_4^{2-}, CO_3^{2-}, HCO_3^{-}, NO_3^{-}, PO_4^{2-} anions. Result of measurements is given in millimol equivalent value (mmol/L) or concentration (ppm) by laboratories. Evaluation of data can be based on the values of Table 4.

Table 4.

Expected effects of the irrigation water salt content on vegetation (ppm)

Element	**Expected effects**				
	None	**Low**	**Medium**	**Strong**	**Serious**
Hydrogen-carbonate	<122	123-183	184-244	245-366	>366
Chlorine, on leaves	<108				
Chlorine, on roots	<144		145-216	217-360	>360
Sodium, on leaves	<69				>
Sodium, on roots	<69		70-207		>207
Lithium	<2.5				
Zinc	<2				
Iron	<1				
Manganese	<1				
Fluorine	<1				
Boron	<0.3	0.31-0.5	0.51-1.0	1.1-2.0	>3
Copper	<0.2				
Electric conductivity mS/cm	<0.2	0.21-0.7	0.71-2	2-3	>3

Total amount of anions and cations

After the final analysis is completed, we receive the total salt content in millimol equivalents (mmol/L). Amount of anions and cations should be about the same. In case the two values differ from each other then either one significant component was missed or the analysis itself was not correct.

The calcium and manganese

Plants can tolerate high Ca and Mg concentration. In nature their presence normally does not harm the species, on the contrary they occur in quantities insufficient for plant needs. For their analysis we need to evaluate the role of the sodium and the hardness of water. Hard water (nk°>16) forms white spots when sprayed on leaves and fruits and it plugs water emitters or the sprinkler nozzles by precipitating inside the irrigation system.

Sodium

Judging the state of sodium is one of the most important act of water analysis. If it does not exceed 3 mmol/L (69 ppm), irrigation above ground does not harm vegetation. When concentration of sodium is higher, absorption through the leaves can result in leaf burning.

Sodium in the soil can indicate salinization (soil compaction) and poisoning. The maximum value of Sodium Adsorption Ratio can be 3. Nowadays horticultural production is normally executed on special cultivation ground, where salinization is not severe due to high clay content. In case plants are grown on natural soil and SAR value is higher than 6, liming is required.

Sulphur

The sulphur content of soils is normally insufficient for plant needs. In case the quantity of sulphur to be found in soil solution is less than 1 mmol/L (48 ppm), it has to be supplemented.

Chlorine

In amounts smaller than 3 mmol/L (108 ppm) do not result in leaf burning. In amounts smaller than 4 mmol/L (144 ppm) do not damage root system.

Hydrogen-carbonate, carbonate, alkalinity

Concentration of hydrogen carbonate (HCO_3^-) below 3 mmol/L (183 ppm) do not cause problems, on the contrary this amount is useful for managing the buffering capacity of water. Higher concentration increases water chemical reaction to a harmful level and results in precipitation or micronutrient utilization problems.

Concentration of carbonate (CO_3^{-2}) is rarely too high in irrigation water; normally hydrogen-carbonate is responsible for the development of alkalinity.

Definition of alkalinity relates to the quantity of acid required for the neutralization of the solution. Hydroxides, ammonium, boron, some of the phosphates, silicates also increase chemical reaction but carbonates show the biggest effect. Relative concentration of three carbon forms (carbon-dioxide CO_2, carbonate ion CO_3^{2-}, hydrogen-carbonate ion, HCO_3^-) to each other determines the reaction and buffering capacity of the system and the clogging process also depends on the stability of the system.

The following process takes place in most horticultural systems.

- From the drip irrigation system water arrives into the cultivation ground. From here CO_2 moves into the air due to pressure change and the increase of temperature:
  $2H^+ + 2HCO_3^- \Rightarrow 2H_2O + 2CO_2 \uparrow$
  as a result, amount of H^+ drops, pH increases.
  In this solution of higher pH, solubility of some salts decreases, precipitation occurs.
  e.g.: when pH is higher than 7,5
  $Ca(HCO_3)_2 \Rightarrow H_2O + CO_2 + CaCO_3$, solid salt separates as lime.

- If we add H^+ ions to the solution by introducing acid, the direction of the reaction changes:

$CaCO_3$ (lime)	$+ 2H^+ \Rightarrow Ca(HCO_3)_2$	highly soluble
2 $CaPO_4$ (phosphate)	$+ 2H^+ \Leftrightarrow Ca(HPO_4)_2$	soluble

Sometimes it is possible that irrigation water (e.g.: rainfall) does not show alkalinity. This is a disadvantage when the smallest amount of acid or acidic fertilizers can seriously decrease chemical reaction. In case chemical reaction of cultivation ground falls under the tolerable value in several occasions, then leaching of water may become necessary. Then we can use potassium-hydrocarbonate ($KHCO_3$).

Ammonium, nitrate, phosphorus, potassium

Allowable concentration of these elements in irrigation water is normally not limited. Under natural conditions they occur in low densities, do not satisfy plant needs. When using sewage or treated waters for irrigation these elements can occur in considerable amounts, so they can serve as nutrients. Quantity of the above ions in treated waters mainly depends on the temperature (because of biological cleaning in treatment plants) so we have to check their concentration several times during the growing season.

Microelements

Low (lower than 0.3 ppm) or high (higher than 1.5 ppm) concentration of boron can cause problems. When quantity is low, supplement is needed; if it reaches the concentration of 1.5 ppm or higher, boron tolerance of the actual plant has to be checked separately.

Copper and zinc quantity is normally measured by laboratory analysis. Their quantity in irrigation water generally does not reflect availability for plants.

Iron and manganese content is very important to define. These elements occur in more than one valence state, another oxygen can be bonded to the same ion in oxidizing agent. The oxides of the cations show different characteristics, their solubility significantly decreases and they form insoluble precipitation inside drip irrigation parts. Presence of these oxides give a yellowish brown coloration to water and give the same colour when sprayed on plants and on the ground.

Fluoride and lithium can occur in significant concentrations at some places. Quantiies of fluoride above 1 ppm and of lithium above 2.5 ppm can be dangerous for some plants.

Electrical conductivity (EC)

Conductivity increases as more and more ion is dissolved in water. Measuring EC does not give us information on the type of dissolved salts so we cannot determine applicability of water for irrigation purposes. Upon the results of field experiments we can conclude that 1 mS/cm (1 dS/m) corresponds to 640-700 mg/l salt content depending on the origin of the water. This range of measurement gives us a rough estimate of Total Dissolved Solids (TDS). Plants respond to different salt concentration in different ways, Table 24. provides a listing of some plants according to salt tolerance.

Some of the salts used as fertilizers e.g. carbamide do not conduct electricity. After applying of such fertilizers EC measurements of the mixed nutrient solution give misleading results because the chemically transformed compounds of the soil already show electrical conductivity.

Chemical reaction, pH

Importance of pH is sometimes exaggerated, we cannot determine water quality based on this single factor. Sometimes high pH values (over 8 pH) can indicate low hydrogen-carbonate and salt content. Reaction of natural waters can vary between 6.0 and 8.0 pH depending on the origin of water. The neutral pH value is 7.0 but for most plants the range of 5.6-6.8 is suitable; in this range most of the significant nutrients are optimally soluble. On natural soils 6.2-6.8 pH, on artificial grounds of low colloid content, 5.6-6.2 pH is recommended. Water of low pH indicates corrosive nature, it damages metal pipes and fittings.

1.4.3. Treatment of clogging hazard and deposits

Treatment is normally carried out by introducing some sort of acid into the Queen Gil irrigation system. The aim is:

- to prevent precipitation of dissolved salts,
- to dissolve precipitated salts,
- to increase the effect of chloride treatment.

Correct treatment does not damage vegetation, because by neutralizing harmful nutrients, acid gets bonded already in the irrigation system, so chemical reaction of dripping water is much higher than that of incoming water.

Prevention

Decreasing the chemical reaction of water to the required pH value of 6 can prevent the formation of lime precipitation. pH value of different waters reacts in a different way to a given quantity of the same acid depending on the buffering capacity. Continuous acidic treatment is needed when irrigation water pH exceeds 7.5 so we can prevent precipitation of calcium- and manganese-carbonate. In case of high ferric and manganese content the above treatment is not sufficient.

Solution

Calcium carbonate, calcium-phosphate and ferric oxide can be dissolved by acidic treatment. Suggested method: set the chemical reaction of water to pH 2 and treat the system for 10-90 minutes. Then we have to flush the pipes till clean water comes out.

Type of acids to be used

Hydrochloric acid. Concentration is 30-37%, it is commercially available in most places. It has a corrosive effect on most materials (even on copper).

Sulphuric acid. Concentration is 77-98%. Highly soluble in water, shows a corrosive effect on most materials.

Phosphoric acid. Concentration is 60-85%. It has a nutritive value. Cannot be used if iron is present in water because that would indicate precipitation reaction.

Nitric acid. Concentration is 60-65%. It has a nutritive value.

Acidic treatment

Treatment is normally done outside of the irrigation season not to influence the development of plants. Short (10-30 minutes) treatment with a solution of pH 2 can be also completed during the irrigation season. Necessary amount of acid for obtaining required reaction level can be determined by laboratory analysis. During treatment we should confirm pH value at different stages of the system.

Required amount of solution can be introduced with the injectors connected to the branches using the energy of irrigation water. The amount of water needed for operation is small therefore we should decrease the diameter of flow after the injector, measure the flow per hour with water-meter then set the stroke number of the pump accordingly and apply concentrated acids into the side tanks.

To set the proper acid dosing we can change the amount of water running through the main line, the concentration of the acid and the stroke number of the pump.

Increasing the efficiency of chloride treatment

Chloride treatment is effective in acidic agent under pH 6. The hypo used as chlorine source increases the pH value of water so maximum efficiency cannot be obtained therefore separately introducing pure acid may also be necessary. To determine the required amount of acid we should complete titration tests. Be very cautious when using acidic and chloride materials.

Treatment of waters containing iron and manganese

The ferrous ion (Fe^{2+}) is the reduced, soluble form of ferric ion, it can be found in oxygen-deficient environment of low chemical reaction. This kind of environment exists in ground water. Pumping the water into the surface releases carbon dioxide, increases pH thereby creates oxidizing environment. The reduced ferrous ion is then transformed into ferric ion (Fe^{3+}) and when deposited, narrows the diameter of outlets and finally clogs the small holes.

The oxidized iron promotes the presence, reproduction of certain bacteria even in very low (0,2 ppm) densities. Bacteria exist in sticky colonies, which gather all sorts of pollutants. Later these colonies separate from the wall of the pipes forming sheets of several millimetre thick thereby accelerating clogging processes. Similar reactions occur in the presence of manganese.

As the first step of prevention we have to define the iron content of water. Above the concentration of 0,2 mg/l we should apply some sort of treatment. Between 0,3 and 1,5 mg/l bacteria will appear, above the concentration of 1,5 mg/l iron is deposited. When reaching 4 mg/l, treatment becomes especially difficult. Furthermore the oxidization-sedimentation-filtering steps should be completed, which are still effective in the presence of iron and manganese. Oxidization can be completed by chloride treatment, aeration.

General method of aeration is the temporary storage of water. When planning the water reservoir, we should consider the following. The inlet and outlet should be located the farthest possible from each other. The basin should be possible to clean. Long but narrow basin works better than square shaped one. We should place the filtering screen of the pump close to the surface, onto the floatation gear to prevent access of deposits into the irrigation system. Inside the reservoir the different organisms can increase in number rapidly, the extraction of which creates a new task, installation of gravel filtering into the system may become necessary. To keep away algae we can use copper sulphate, which damages aluminium parts.

Treatment of waters containing organic matters

Treatment is done by adding chlorine. The effects are: destroying algae and other living organisms; decomposition of live and dead organic matter; preventing the binding and deposition of particles; oxidization and precipitation of manganese and iron to be extracted by filtering. Most plants are not sensitive to normal amount (continuous application of maximum 10 ppm and single treatment of maximum 50 ppm free Cl) of chlorine. Sensitivity of plants also depends on their stage of growth and on the characteristics of soil. Young plants on sandy soils are more sensitive than older ones on clay soil. Chlorine reacts with ammonia therefore nitrogen and chlorine have to be added separately. Induced effect depends on the concentration of chlorine, the chemical reaction of the solution, duration of treatment and the temperature. The required doze depends on the method of injection, the water quality and the quantity of live organisms. For exact portioning we should use pumps employing dozes of standard volumes.

To calculate the doze we should consider the following:

a. concentration of hydrogen-sulphide, for the neutralization we should apply the same amount of chlorine,
b. at the oxidization of iron and manganese we should calculate 0,6 ppm chlorine for 1 ppm of iron, manganese content,
c. for the treatment against algae the doze should be big enough to give 1-2 ppm of free chlorine at the pipe emitters for 25 minutes.

There are several methods to measure the amount of free chlorine, the reagents show different coloration for the different chlorine concentrations. The presented colour has to be compared to the colour scheme of the certain reagent then we can read the value.

Application methods:

a. in case of continuous application, we have to introduce chlorine in the same concentration (1-10 ppm) at each irrigation during the whole season,
b. in case of cyclic application we have to introduce chlorine in a doze of 10-20 ppm several times a day,
c. in case of extra application we have to introduce 50-200 ppm chlorine for five minutes once during the irrigation cycle.

Materials to be used:

- Liquid hypo (NaOCl) of maximum 15% chlorine content. Na^+ ions will be released in the water increasing the pH of water thus decreasing effectiveness of treatment. The Na^+ ions can harm vegetation and induce a salinization process in the soil.
- The lime chloride ($Ca(OCl)_2$ is either in powder format or applied in tablets. It increases slightly the pH of water.

1.5. Water sources

Rivers, channels

The best water sources are the different streams, rivers, irrigation channels because their salt content is low, their temperature meets irrigation purposes, pumping and injecting the water into the irrigation system is easy and cheap.

Depending on the season and occurrence of floods they can contain many organic and inorganic materials. In case of channels the reason for this can be the double utilization of diverting-irrigating inland waters where the higher concentration of salts is caused by inland waters remaining in the area. Around some newly constructed channels considerable amount of salts can be solved from the soil profile. Evaporation of water, the process of drying out can also increase salt concentration.

Lakes, reservoirs

For the management of water reservoirs bordered by natural soil walls, it is important to keep the sides in good condition to help filtration. Proper slope and grass planting of the sides prevents degradation of the soil. The reservoirs can be also used for deposition of clay and loam particles. Size of deposited particles also depends on the water movement; deposition rate of sand particles is about 1 m/hour. Clay particles require several days to be settled. Adding chemical materials can induce precipitation of floating particles. When the water has high iron content, smaller reservoirs, tanks can be used to oxidize and deposit dissolved iron and manganese. For speeding up the process, artificial aeration (e.g.: spreading the incoming water) can be applied.

These water bodies contain considerable amount of living organisms. During the year these organisms change in mass and composition according to the physical, chemical and biological characteristics of water. To filter living organisms we should use disk filter for smaller amounts and gravel filter for higher water utilization. In the lakes we should connect the suction line of the pump half way between the bottom and the surface. Thereby we can prevent suction of organism-rich upper layers or mud, organic materials deposited on the bottom.

Their salt content can be very variable depending on the connection to a natural water source; the salt content becomes more concentrated due to increased evaporation during the summer. In water bodies without outflow the salt content resembles that of the ground water. The danger of salinization greatly increases when using these waters for irrigation.

When water tanks are used, we should keep them empty between the turns of irrigation or we can prevent the appearance of some organisms using blue-stone if the operation requires the tanks to be filled always. Suggested concentration is 2 ppm. Connect the siphon at least 10 cm above the bottom to prevent suction of deposit.

Wells

The organic matter content is low; solid particles occur in various densities and proportion, the same applies for the salt content. Among salts, calcium (Ca) and manganese (Mg) compounds can occur in significant amounts. Due to change in pH, pressure or temperature characteristics, these elements precipitate as grains inside the system and then water carries them to the outlets where the small holes become clogged. If these elements stay in solution, they can serve as the main source of clogging at the outlets when drying out. Iron (Fe), manganese (Mn) and sulphur (S) compounds can be also found in various amounts. Problems of soil salinization arise if the sodium (Na) content is high.

This is also true for the water in public water network where filtering normally does not satisfy the microirrigation demands.

Along the rocky shores of rivers good quality water and rich water supply is expected. Water taken from the wells – if the iron and manganese content is low – should be supplied directly into the irrigation system thereby we can prevent pollution.

Treated sewage waters

They normally contain lot of salts and organic material of various amounts depending on the method and level of treatment. If used for irrigation we have to consider the presence of live organisms and heavy metals harmful to health and should not use this water source for irrigating vegetables.

1.6. Measuring the ground water content

Continuous measurement of the ground water content can be very difficult because our interest is not only the absolute water content but also the available amount, which can be taken by the plants without loss of yield. This amount varies depending on soil type and plant species. The distribution of water in the soil is not uniform, it differs from one layer to another and we have to summarize the values considering the length of the roots. We should select a typical point for the measurement or take multiply samples. Microirrigation has the advantage of the small moisture range, which helps to prevent the cracking of soil, the sign of drying out and the results of salt concentration increase in the soil solution, which would make measurements more difficult.

Tensiometers

After time the water inside the fine porous cup placed in the soil will reach equilibrium, at which time the potential in the soil is the same as that in the tensiometer. Due to the ground water potential of the solid particles water is drawn through the cup into the adjacent soil. The air from the outside does not enter inside the tensiometer thus creating vacuum, which can be measured by manometer.

When ground water content increases, water filtrates into the cup decreasing the vacuum. Connecting the cup to a water column, change of the column height indicates present equilibrium status. Water has to fill up the system hermetically.

To make interpreting easier a gauge or mercury meter is used to measure tension. The tensiometer indicates the present equilibrium status and water potential of the soil so we can directly read the available water content for roots. There is no need for calibration of the different soil types.

Before installing the tensiometer (Figure 2.) keep it in water till it fills up totally. At the sampling site sink a hole of the size to fit properly (normally this is the ½" diameter of the tensiometer). After installation fill it up with boiled, deionised water and close it tightly. Be careful not to leave a gap after sinking because that would collect the rain water giving an unreliable measurement of the ground water content. Protect it against warming up with shading when the sunshine is strong. Do not leave it on places endangered by frost because of its water content. When mud sticks on the ceramic cover after use, thoroughly rinse it with water, fill it up and leave the closing valve open for 10-15 minutes to let the leaking water rinse the pores of the cup.

For plants with a root system deeper than 30 cm we should place two tensiometers, one into the upper and one into the lower root zone. The upper one tells us when to start watering and the lower one shows when to finish it. If we decide to place only one tensiometer, that should be installed to 3/4 of the total root depth.

Presenting the measured values on date-centibar diagram illustrates the water supply during the growing season.

The water equilibrium status is read in centibars. The meaning of the ranges is as follows:

0-10	The root zone is filled with water, there is not enough oxygen for plant development.
11-25	Moisture content and aeration of soil is ideal, water content meets water capacity.
26-50	Range for irrigation. We should start watering according to the plant needs.
51-70	Production is already affected by the dryness of the soil.
above 70	The soil is very dry.

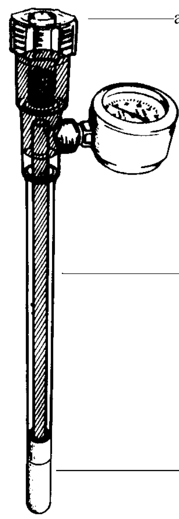


Figure 2.: Tensiometer

The upper limit of the tensiometer working range is about 80 centibar. Above this value the soil shrinks and causes cracks to open in the surface, which prevent proper connection of the cup with the soil, air enters the tensiometer so measurements cannot be taken.

Natural connection between the soil and the ceramic cup is formed after 2-3 irrigation, thereafter reliable measurement is possible.

Advantages: the soil does not have to be disturbed during measurements; it can be installed for a longer period; installation is easy; data can be easily recorded automatically; salt content does not affect accuracy of measurements; it is cheap. Disadvantages: when soil is dry it is difficult to reach appropriate connection to the soil; accuracy is not adequate in the wet zone; applicability is limited by soil texture. Applicability is limited on sand, wetlands and on cultivation grounds of similar structure. For these textures we have to use a special type, developed for these purposes.

Drying oven

A sample of moist soil is weighed and then dried in an oven on a temperature of 105 °C and finally weighed again. The water lost by the soil represents the soil moisture content. This method can be used in the full moisture range, it is not sensitive to temperature and salt content and gives accurate result. Disadvantages: sampling requires soil disturbing, labour demanding, requires multiply sampling to compensate for sampling errors and the measurements cannot be reproduced.

Measuring electrical resistance

When certain porous materials such as gypsum or Fiberglas are placed in moist soil they absorb water until equilibrium is reached. When the small blocks are embedded with electrodes, measurement of the electrical resistance in the block gives an estimate of the water content in the surrounding soil. Accuracy is below ±2%. Advantages: the soil does not have to be disturbed during measurements; it can be installed for a longer period; method is easy; data can be easily recorded automatically; it is inexpensive. Disadvantages: it is difficult to ensure proper connection when the water content of the soil is variable; all units have to be calibrated; measurements are influenced by the salt content and temperature of the soil; accuracy is moisture dependent.

Measuring the dielectric constant of the soil

a. Measuring electrical capacity

The dielectric constant of the soil depends on the water content. When the soil is dry, the value is 2-4 on the wet soil it is around 80. The sensor is a metal stick pushed into the soil, where the metal part is insulated from the body creating the capacitor film. Mistakes can be eliminated when only the change of the soil moisture content not the actual water content is measured.

Advantages of the measurement: the soil does not have to be disturbed during measurements; method is easy; data can be easily recorded automatically; it is inexpensive. Disadvantages: salt content above 0.3% total content and change in soil volume has an influence on the results; calibration is necessary.

b. Time Domain Reflectometry (TDR)

The method is based on sensing the reflection of short waves as they pass through the soil, the transit time is related to the soil's moisture content. Electrodes pushed into the soil do measurement. Besides the water content we can also measure salt content. This analysis is fast, accurate and easy to automate. The method is expensive, have been developed recently.

Neutron scattering

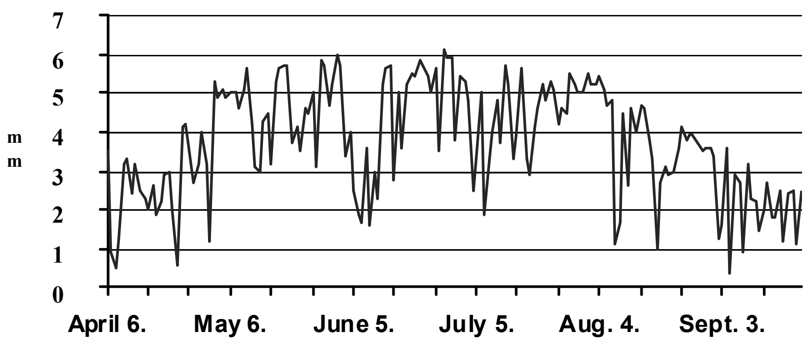
The hydrogen atoms reduce drastically the speed of fast-moving neutrons, the number of scattered slow neutrons can be measured. Under continuous output the number of the scattered slow neutrons relates to the volumetric water content of the soil. The method is expensive, requires specialist and licence, therefore adoption field is restricted. Advantages: it is not salt and temperature sensitive, can be applied in the whole moisture range, easy to reproduce, local measurement is possible. Disadvantages: meters are disturbed by organic substances and certain elements; calibration is necessary; not accurate in surface layers (till about 30 cm deep).

2. Irrigation scheduling

Irrigation scheduling covers setting the water amount and irrigation time depending on cultivation region, plant species, soil types and irrigation equipment. The aim is to time frequency and amount of irrigation in such way to prevent yield losses. The planning cannot be based purely on visual estimation of the grower or on practical experience of some years. To time the irrigation and adjust the amount of water correctly we need to perform measurements, calculations.

Figure 3.

Potential evapotranspiration values of corn in the year 1990, Figure by (Huzsvai, 1995)



Proper time of irrigation depends on the climate (intensity of sunshine, temperature, relative humidity of the air, wind speed, amount of rainfall), the available ground water content and on plant needs. In the semiarid and sub humid climates rainfall is common during the irrigation season and we have to take this into account. Single rainfall of less than 5 mm does not affect significantly the ground water content.

The *evaporation* is a physical process, here it relates to the evaporation of the bare soil surface, which depends on the temperature and on the movement and humidity of the atmosphere. The *transpiration* from the leaf surfaces is also affected by the factors described above but this connection is not linear because the plant itself controls water loss with the stomata. These processes are not only affected by atmospheric but also biological and soil characteristics. It is very difficult to measure transpiration on the field therefore plant water loss has to be defined by measuring evaporation under the same conditions and modifying it by the plant specific factors. The combined loss from these two processes, the *evapotranspiration* (ET) of vegetation (Figure 3.) is responsible for the total water vapour loss from soils. The ET value determines the overall rate of depletion of a vegetation minimum 1 ha in size. When development and growth of the plants is not restricted because of insufficient water source (excess water or shortage), the vegetation is healthy and nutrient source is sufficient. When the land cover is complete, evaporation at the soil surface compared to transpiration from the leaf surface is negligible, stays below 5%. In this case the required amount of irrigation water is about the same as the transpiration from the leaf surface.

Irrigation time defining

Grower's feelings

Defining the start of the irrigation is based on the practical observations of the soil, vegetation and weather characteristics. The grower observes the drying of soil or the cultivation ground, the wilting of plants or lifts up the container of the plant to feel the water content and decides upon his experience, knowledge whether irrigation should be started. This method is widely used despite the fact that water portioning is very problematic. It is very difficult to estimate the actual water content of the soil, wilting already indicates stress and restricts full development and production. Another disadvantage is the need for continuous control, vegetation have to be checked several times each day.

Longer experiment helps us the use of clock relay to start irrigation. We can set the start, the duration of irrigation, or both parameters with the help of the electronic, hybrid or mechanic clock relays. We can water the cultivation ground several times a day, once a day or once in every couple days depending on the ground and the plant needs. It is possible to build in a detector, which gives a signal when penetration of water reaches the required depth or operates irrigation system till the start of water runoff. Or simply we can set the time of turning the system on and off with a mechanical switch. In this case we have to take into account the seasonally changing evaporation, the development of the plant and increase or decrease the duration of watering accordingly. If we have a choice, we should select the system offering the most watering per day.

Mass measurements

The most exact method for estimating the water need is the continuous measurement of the ground water content. Although the sampling method (measuring the mass of the sample, oven drying and then measuring again) takes a lot of time and it is difficult to repeat. A more practical method is placing the culturing pots on a balance and recording data continuously. Based on the daily recordings we can isolate the changes due to plant development and calculate the water requirements of the whole vegetation. The difficulty of the method is the need for continuous data recording and selecting the representative individuals.

Measuring the ground water content

The most common method is the use of the tensiometer. Carefully choose the type of the instrument; different cultivation grounds utilize different constructions the best. Some tensiometers have electronic signalling to directly control the irrigation system. In this case the depth of the instrument and accordance with the irrigation system installed and the amount of water is very important. When using high intensity sprinkler systems, water also fills up the gravitational pores. Water in these pores will move downwards after irrigation stops, the bottom of the wet zone will then be under the tensiometer. On the other hand application of the drip irrigation system does not enlarge this zone. Sensors measuring the dielectric coefficient of the soil can also be used effectively to start the irrigation system automatically or manually.

In greenhouses or on arable land it is suggested to place sensors in several places and at least in two depths.

Besides installing moisture sensors we also need to take safety precautions. Mechanisms starting irrigation after a certain minimal or maximal time or automatically setting the minimal or maximal duration of irrigation can be installed.

Moisture sensors can be also used for prohibiting automatic timing.

Using evapotranspiration models

Evaporation pans

To determine the level of transpiration and the amount of water to be added, we can use the results of evaporation pans during the growing season. The method gives an estimate of the sunshine, temperature and humidity effects on the evapotranspiration of the plant environment to be watered. Correctly choosing the type and placement of the pan we can follow the transpiration of plants. But we also have to consider the development of plants and the different transpiration rate of the species therefore different multiplication factors are used for calculation.

The internationally used "A" type (U.S. Weather Bureau) evapotranspiration pan is round, with a diameter of 121 cm and 25.4 cm (10") in depth. It is built from galvanized metal plate. We should place it horizontally inside the vegetation about 30 m far form the edge so the transpiration conditions will be identical to that of the plant studied. We should place the pan on a wooden screen about 15 cm above the soil surface. That way we can prevent transmission of thermal energy from the soil. When filled up, water should be 5 cm below the edge of the pan but not lower than 7.5 cm. Results can be affected if birds drink from the water therefore we should cover the pan with a loose net or place another pan in the area filled up to the edge. Then birds will favour this other pan to drink from.

Transpiration of the plants can be calculated by the following formula:

$ET_c = ET_0 \times k_c$

where:

ET_c = transpiration of the plant, mm
ET_0 = evaporation at the pan surface, mm
k_c = factor of the plant

The 125 days of plant development can be divided into four typical periods by the transpiration of plants:

1. early stage (about 10% plant cover, 20 days) $k_c = 0.35$
2. growing stage (about 70-80% plant cover, 35 days) $k_c = 0.35\text{-}1.25$
3. full development (full plant cover, 40 days) $k_c = 1.25$
4. ripening (30 days) $k_c = 0.60$

The factors of stages 1. and 2. are normally the same for each plant and Table 5. lists the factors for stages 3. and 4.

Water demand can be calculated by adding evaporation at the soil surface and water losses to the transpiration of the plants.

Calculation of the irrigation water demand:

$$\ddot{O}v = \frac{ET_c}{\left(1 - \frac{E}{100}\right) x \left(1 - \frac{v_e}{100}\right)}$$

where:

Öv = irrigation water demand
ET_c = transpiration of the plant (mm),
E = evaporation at the soil surface (%),
v_e = transpiration and other losses (%).

Table 5.

Transpiration factors (k_c) of plants at different development stages (Doorenbus & Pruitt, 1984.)

plant	development stage	RH min < 20 %	
		wind speed 0-5 m/s	wind speed 5-8 m/s
Potato	3 4	1.15 0.75	1.2 0.75
Sugar-beet	3 4	1.15 1.0	1.2 1.0
Melon	3 4	1.0 0.75	1.05 0.75
Tobacco	3 4	1.15 0.75	1.2 0.8
Onion	3 4	1.05 0.8	1.1 0.85
Cruciferae	3 4	1.05 0.9	1.1 0.95
Corn	3 4	1.15 0.6	1.2 0.6
Sunflower	3 4	1.15 0.35	1.2 0.35
Paprika	3 4	1.05 0.85	1.1 0.9
Tomato	3 4	1.2 0.65	1.25 0.65
Lettuce	3 4	1.0 0.9	1.05 1.0
Dry pea	3 4	1.15 0.25	1.2 0.25
Soybean	3 4	1.1 0.45	1.15 0.45
Cucumber	3 4	0.95 0.75	1.0 0.8
Green pea	3 4	1.0 0.9	1.05 0.9

RH= relative humidity

Example: watering the paprika in August, in the development stage 3., wind speed is lower than 5 m/s. That means the plant factor is 1.05, transpiration of the evapotranspiration pan is 5 mm. Land is covered, evaporation is 5%.

$$\text{Öv}\ \frac{5x1.05}{0,95} = 5.5\ \text{mm}$$

According to the conditions above the daily water demand of the paprika is 5.5 mm, which means 5.5 l water per 1 m^2 and 55 m^3 water per 1 ha.

For irrigation we have to apply the water amount transpired by vegetation since the last portion of water, considering the rainfall as well. Input of excess water results in percolation and cannot be utilized by the plant. If we have a water deficit, quantity and the quality of crop yield will be insufficient. Although we have to remember that plant water need changes considerably during the growing season.

Table 6. presents watering characteristics and general needs of different plant species in the growing season.

According to the studies performed, irrigated plants take water from the rooting zone to a different extent. In case of microirrigation this uptake rate is 60-30-7-3 from four equal zones of the root zone.

Based on mathematical models

There are several mathematical models existing to define evaporation. For the Blaney-Criddle method we need to know the average daily temperature values of the atmosphere. Other influencing factors are included in the table. The radiation method evaluates the air temperature and solar energy. The Penman method means the analysis of temperature, wind, solar energy and relative humidity.

Table 6.

Some characteristics of plants and irrigation in the dry years of 20% incidence

name	depth of the root zone (m)	p factor for calculating water needs	water need in the growing season (mm)	irrigation water need (mm/year)
potato: early	0.6-0.9	0.25	300-350	80-120
late	0.9-1.2	0.30	350-500	120-200
sugar beet	> 1.5	0.5	550-600	180-250
sweet corn: early	0.3-0.6	0.45	250-300	50-100
late main crop	0.9-1.2	0.45	300-450	100-200
early secondary crop	0.3-0.6	0.45	250-300	100-150
tobacco	0.3-0.8		400-500	250-350
watermelon	1.2-1.5	0.35	400-500	100-150
lettuce: early	0.3-0.6	0.45	120-200	50-80
relatively early	0.9-1.2	0.45	200-350	80-120
relatively late	0.9-1.2	0.45	350-500	120-180
late	1.2-1.5	0.45	500-600	180-250
Brussels sprouts	0.3-0.6	0.35	600-700	200-300
corn seeds	0.6-0.9	0.55	350-500	100-220
grains	0.9-1.2	0.50	400-550	150-200
paprika: sweet	0-0.3	0.25	500-600	250-350
spices	0.3-0.6	0.30	450-550	200-250
tomato: regulated	0.6-0.9	0.5	300-400	120-150
half regulated	0.9-1.2	0.5	400-450	150-180
continuous yield	1.2-1.5	0.5	450-550	180-220
honeydew melon	0.9-1.2	0.35	350-450	80-120
carrot-parsley	1.2-1.5	0.50	520-620	150-200
soybean	0.9-1.2	0.45	400-500	120-180
cucumber: seed and salad	0-0.3	0.5	300-400	120-180
regular cultivation	0-0.3	0.4	400-450	180-230
support system cultivation	0-0.3	0.35	450-550	250-350
celery	0.3-0.6	0.35	550-650	250-350
green been: main crop	0.3-0.6	0.50	130-180	30-80
secondary crop	0.3-0.6	0.45	150-200	80-120
green pea: main crop	0.3-0.6	0.60	130-180	30-50
intensive grassland	0.3-0.6	0.35	600-700	300-400
medic	> 1.5	0.60	600-700	200-300
other legumes	> 1.5	0.55	600-700	250-350
apple, pear: small	0.6-0.9	0.40	500-600	150-250
medium size	1.2-1.5	0.50	500-600	100-180
grape-vine	> 1.5	0.5	520-600	100-150
grape	> 1.5	0.5	570-670	150-200
strawberry	0-0.3	0.15	450-550	100-120
raspberry	0.6-0.9	0.35	500-600	120-150
peach	0.9-1.2	0.50	450-550	100-150

Irrigation timing can be determined by ground water potential, measured by the method described in step 1.6.

Irrigation timing can also be determined by measuring the water potential of the green plant. The plant, which is supplied well with water shows water loss on lower pressure. Measurements can be completed by pressure bomb. The leaf or the soft part of the plant has to be clamped into a rubber baffle ring so that we can see the vascular bundle of the stems then place it into the instrument. Pressure is created by a nitrogen tank. By slowly opening the valve of the tank, on the gauge of the chamber we can read a certain pressure value at which a liquid drop appears at the end of the transport system. The water drop occurs at different pressures for each plant, comparing the measured value to laboratory analysis we can conclude the plant water supply and thereby define the starting date of irrigation.

2.1. Computer based irrigation control systems

The aim of the irrigation control systems is to ensure the conditions for plant growth and to optimize water utilization. Control includes calculation and portioning of the required water amount, distribution of nutrients and chemicals, adjustment of the temperature within greenhouses and operation of a failure signalling system. Part of the data for analysis can be an annual meteorological dataset. The drawback of this dataset is the annually changing weather, average year rarely occurs; the value of the annual ET can differ from actual by 10-25%. Monthly deviation can be even larger, about ±50%. Therefore the aim is to measure all the necessary data locally, automatically and continuously. This way all the data are recorded during data entry and analysis can be completed afterwards.

The users receive and IBM PC compatible computer program, which includes detailed local monthly data or for a whole decade to calculate water utilization and plan irrigation rotation. This program can be found inside the book of SMITH,M.: 1992. CROPWAT A computer program for irrigation planning and management 5.7. (Irrigation and Drainage Paper 46. FAO, Rome.). Updated program (1995 November) is the 7.0 version. This version is easier to use, it is possible to input daily the amount of rainfall and the data of "A" type pan for defining the reference evaporation and the result of the calculations for each decade is included. These parameters allow the program to be used in practice.

The program is used for:

- planning irrigation rotation, including different varieties under field conditions
- evaluating irrigation programs by their effect on water utilization and production development,
- simulating the change of crop yield without irrigation and with insufficient water supply.

The program starts by calculating the reference evapotranspiration (ET_O) with the Penman-Monteith method or by inputting the values. The necessary data: geographical location, temperature, relative humidity, number of sunny hours and wind speed. The daily average or the daily maximum and minimum temperature can be chosen for input.

Calculation of plant transpiration is done in three steps.

1. Input of monthly evaporation and rainfall. Evaporation can be input by entering the actual data or by inserting the results of the above calculation. There are several methods offered by the program to calculate the utilization of monthly rainfall.
2. Recording plant characteristics. Besides manual input we can also use or modify sample files. The development of the plants can be divided into four periods. We have to define the length, evaporation coefficient, the depth of the root zone, the critical disposable water content for each period and the effect of dry periods for the crop yield in the actual development stage.
3. Inputting the time of sowing.

The table of results lists transpiration of the plant and the irrigation water demand for one day and for a decade.

Calculation of rice flooding requires different method.

The irrigation schedule cannot be planned independently; we need to select from the above databases. The calculation gives the complete water balance based on the data input. Then we can enter the soil characteristics. We need to know the amount of disposable water, the original soil moisture content, the maximum depth of the root zone and the maximum level of water penetration.

There are two options to calculate the irrigation schedule:

1. The length of the period between two irrigation cycles, the time *intervals* (irrigation rotation).
2. Amount of water to be output (water portion) for one irrigation cycle.

Both options provide further choices to define timing of the irrigation. E.g. critical soil moisture content, fixed duration, certain crop yield decrease, required field capacity.

The table of results includes the number of irrigation cycles, the intervals between the cycles, time of the irrigation, development stage of the plants, available water content, the actual evapotranspiration rate, the average evapotranspiration, shortage of water, water loss, the amount of irrigation water in millimetres, the required water flow of the source.

Summarization of the data can be found in a separate table, where we can also find information in the bottom line about expected production decrease when irrigation does not fulfil plant needs. Analysing data we can decide whether to change the initial conditions in order to reach better water utilization and increase production.

The program described above can be used only when continuous instrumental monitoring of the ground water content is possible. The application provides a good chance to study the relation of different factors to each other. Running the program with daily data input provides a good base to decide the time of irrigation turns.

3. Nutrient solution

We have to add soluble nutrient for the plants because only this form can be utilized. The origin of nutrients is optional, the Ca element at the root hairs is not labelled whether the origin is limestone (inorganic fertilizer) or cattle dung (organic fertilizer). Characteristics of Ca^{2+} did not change if the ion comes from the rumen of the cattle or when it settled down on the bottom of the sea 1 million years ago. When we add nutrients in a soluble form we can save the different decomposition and transformation processes, which would take place with regular fertilizing. We cannot control the complex utilization processes in detail (there is no way to artificially change factors like temperature, chemical reaction) so the rate and quantity of available nutrients is not always sufficient. With adding nutrients in solution we can always ensure proper quantity and rate of nutrients according to the species and development stage of plants and the environmental conditions. Daily control is also possible, to change the quantity and rate of nutrient according to the light and temperature conditions of the actual day or we can even add a nutrient form, which is easier to absorb (nitrate ion instead of ammonium) under colder circumstances.

One of the main advantages of the Queen Gil irrigation tape is the possibility to output exact portions of plant nutrients. Continuous output of the nutrients is necessary because irrigation creates only a small wet zone around the root system. Availability of nutrients is optimal in this zone but their amount is smaller than further from the plant stem. Therefore microirrigation without the output of nutrient solution can result in production loss.

Nutrient uptake of plants is not uniform during the whole development. The concentration and rate of necessary nutrients to each other is continuously changing. For optimal quantity and quality of crop yield we need to monitor plant needs and that is easy to compensate by nutrient solution. Fertilizers containing macro- and microelements perfectly soluble in water are available. Fertilizers containing sulphate and phosphate can help to decrease the chemical reaction of water and to prevent precipitation of lime.

Advantages of adding nutrients in solution:

- The roots can absorb the water and the nutrients uniformly because the fertilizers are in solution. The solid particles of different bulk densities do not form layers during transportation, which would make the input scattered. In a well-planned water system the deviation of output does not exceed ±2.5%.
- Nutrients in the solution are transported directly to the roots, P and K is available for nutrients immediately.
- Output is easily done any time depending on the development stage of the plant, adding the actually necessary quantity and concentration.
- There is no need to drive or walk over the area so there is no compaction damage. Inexpensive portioning methods, equipments can be applied, this is an economical and energy saving method.
- Frequent output of small concentrations prevents quick root destruction caused by a single large amount of fertilizer applied directly to the plant therefore this method is safe.
- The continuous output of small portions according to the plant needs prevents leaching and binding.
- The continuous and well-planned input of nutrient solution increases crop yield with 20-25%, improves quality.

In scientific literature input of nutrient solutions is called fertigation, combination of the words fertilization and irrigation. This has a different meaning than simple nutrient addition. Fertigation includes planned nutrient supply depending on actual plant needs, verified by leaf analysis to accomplish a certain amount and quality of crop yield.

Composition of fertilizers has to be considered because they can increase the speed of clogging processes when reacting with the soluble salt content of the water. The phosphorous acid or fertilizers forming phosphoric acid in solution create insoluble iron, calcium and manganese salts. Concentration of calcium should not exceed 6 mgeq/l. Ground waters include large amounts of salts of the above elements therefore we have to pay special attention to selecting the type of fertilizer to be used, it is suggested to ask the help of a specialist before using new combinations.

When defining the concentration of the solution and for portioning we should also consider the salt tolerance of plants, which is the lowest at germination.

Table 8 lists the salt tolerance of plants according to different levels of crop yield decrease and the highest salt content tolerated by plants is also included. These data can be used to define the amount of water necessary for leaching.

According to recent research the salt tolerance of tomato towards the concentration of irrigation water is high, EC_W value can even reach 3 without resulting in the loss of crop yield.

3.1. Fertilizers

Characteristics of fertilizers to be used for fertigation:

- total solubility (less than 0.02 percent solid residues),
- fast solution in water (about 20 minutes),
- fine texture (particle sizes between 0.6-0.15 mm),
- high nutrient concentration in the base solution,
- no reaction with the salts in the water solution,
- should have a minimum content of conditioner materials (less than 150 ppm per dry matter content).

Solubility of fertilizers (Table 7.) is one of the most important characteristics to check in order to decide what concentration of the different nutrients is required in the mother solution at a certain temperature. Solubility can be a process of temperature loss and then the temperature of the solution decreases. This is especially true for the solution of ammonium nitrate and urea where the side of the pan becomes frosted. Use 20% more water than the amount calculated from solubility of fertilizers, to prepare the mother solution. This is necessary because the temperature can change resulting in saturation of the prepared solution and precipitation of the salts. This can be especially dangerous when using nutrient solution pumps because the crystals formed can damage the surface of moving parts.

For the application of chloride containing fertilizers we should consider the salt tolerance of plants. When adding calcium- and manganese nitrate the soil pH should not exceed 6 and we should not apply phosphoric acid to prevent precipitation.

Table 7.

Solubility of fertilizers to be used for fertigation

	Solubility g/l	
Name of fertilizer	**at 0 °C**	**at 20 °C**
ammonium-chloride	297	-
ammonium-nitrate	1183	1950
mono-ammonium-phosphate (MAP)	227	282
ammonium-sulphate	706	760
potassium-chloride	280	347
potassium–nitrate	133	316
potassium-sulphate	69	110
calcium-nitrate	1020	3410
manganese-nitrate	-	423
mono-calcium-phosphate	-	18
phosphorous acid		5480
urea	780 (5 °C)	1193

Fertilizers containing ammonium can increase the water pH till 11, which results in the fast precipitation of calcium- and manganese carbonate.

The N containing fertilizers have high solubility in water; do not react with the nutrients in solution except with ammonium-sulphate, which precipitates as $CaSO_4$ in calcium rich water.

From the P fertilizers only the ones listed in Table 7. can be used for fertigation. All the P fertilizers can result in clogging of the system if the chemical reaction of water is higher than pH 7.5 (Figure 4.). The speed of the clogging process depends on the amount of calcium, manganese and iron elements.

The mono-ammonium-phosphate (MAP) has a high solubility in water but when the calcium content of irrigation water is high, the phosphor precipitates as dicalcium-phosphate and advances the clogging of drip irrigation parts.

K fertilizers do not result in any precipitation reactions with dissolved nutrients except K_2SO_4, which can react with the calcium in high concentration. When the plant is not sensitive to chlorine content, the use of KCl is suggested because it is the cheapest and easiest to dissolve.

Table 8.

Salt tolerance of plants according to estimated loss of crop yield by the salt content of the soil and irrigation water (mS/cm) (Ayers & Westcot, 1976)

Plant	**100 % full crop yield**		75 % of yield		50 % of yield		Maximum
	EC_e	EC_W	Ec_e	EC_W	EC_e	EC_W	EC_e
Vegetable crops							
Bean (Phaseolus vulgaris)	1.0	0.7	2.3	1.5	3.6	2.4	7
Broccoli	2.8	1.9	5.5	3.7	8.2	5.5	14
Red beet	4.0	2.7	6.8	4.5	9.6	6.4	15
Sorghum	4.0	2.7	7.2	4.8	11.0	7.2	18
Sugar beat	7.0	4.7	11.0	7.5	15.0	10.0	24
Lettuce	1.3	0.9	3.2	2.1	5.2	3.4	9
Corn	1.7	1.1	3.8	2.5	5.9	3.9	10
Paprika	1.5	1.0	3.3	2.2	5.1	3.4	9
Tomato	2.5	1.7	5.0	3.4	7.6	5.0	13
Carrot	1.0	0.7	2.8	1.9	4.6	3.1	8
Strawberry	1.0	0.7	1.8	1.2	2.5	1.7	4
Soybean	5.0	3.3	6.2	4.2	7.5	5.0	10
Squash	1.8	1.2	4.4	2.9	7.0	4.6	12
Sugarcane (Saccharum officinarum)	1.7	1.1	5.9	4.0	10.0	6.8	19
Cucumber	2.5	1.7	4.4	2.9	6.3	4.2	10
Red onion	1.2	0.8	2.8	1.8	4.3	2.9	8
Fruit crops							
Apricot	1.6	1.1	2,6	1,8	3,7	2.5	6
Peach	1.7	1.1	2,9	1,9	4,1	2.7	7
Apple, pear	1.7	1.0	3,3	2,2	4,8	3.2	8

EC_e = electrical conductivity of the saturated soil extraction
EC_W= electrical conductivity of the irrigation water

3.2. Conversion tables of nutrient input

N - P_2O_5 - K_2O content of fertilizers in mass percentage

Amount of macronutrient is normally expressed in percentages, which shows the mass content of N - P_2O_5 - K_2O in the fertilizer.

1 % in 1 kg = 10 g

Example: The MEGASOL pink contains (16-8-24) 16 % mass content nitrogen, 8 % mass content P_2O_5 , 24 % mass content K_2O or 1 kg MEGASOL pink contains 160 g nitrogen, 80 g P_2O_5 and 240 g K_2O.
A package of 25 kg MEGASOL pink contains 25 x (16,8,24 %) equals 4000 g (4 kg) nitrogen, 2000 g (2 kg) P_2O_5 and 6000 g (6 kg) K_2O.

Converting P — P_2O_5, K — K_2O

The result sheet of soil analysis indicates free P, K elements. To convert these values into the amount of P_2O_5 , K_2O we need to use the following forms.

	x 2.29			**x 1.2**	
	⇒			⇒	
P	⇐	**P_2O_5**	**K**	⇐	**K_2O**
	x 0.437			**x 0.83**	

Example: From the above elements the 25 kg MEGASOL pink contains 4000 g free nitrogen, 874 g free phosphorous, 4980 g free calcium.

ppm

Concentration of nutrient in the water and solutions can be expressed in ppm (**p**arts **p**er **m**illion).

1 ppm = 1 mg/kg (1 mg/litre) or 1 g/m^3 water
10 000 ppm = 1 %

Mass per volume

Amount of dissolved nutrients can affect the mass per volume of the solution. This can be expressed by the calculation:

$$\gamma = \frac{t(mass)}{v(volume)} \qquad \mathbf{g/\ cm^3,\ kg/dm^3,\ tons/m^3}$$

Example: When 150 litre solution contains 25 kg of the MEGASOL pink fertilizer of 175 kg in weight, the bulk density is 1.166 kg/dm^3.

3.3. Preparing nutrient solutions

To plan the composition of solutions we should consider the following:

a. it should not clog the system or damage the materials,
b. should be safe to apply on the field,
c. mixed salts should form solution,
d. composing parts should not react negatively with each other and with the salt content of the water.

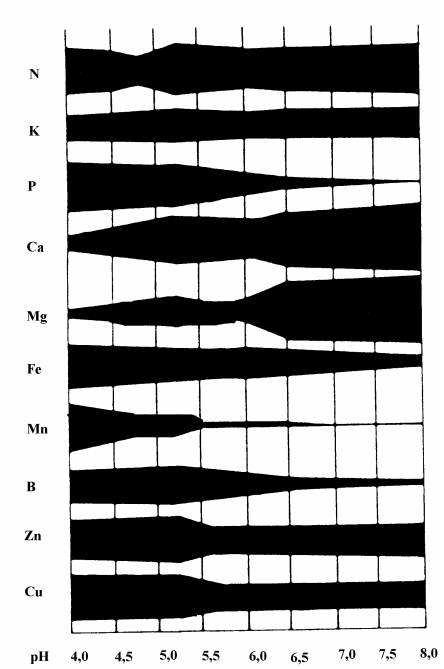


Figure 4.: solubility of nutrients inside the tank

Before applying new type of solutions we should always complete combination tests. In a transparent bottle mix the solution to be used with the solvent of irrigation water. After two hours check the content of the bottle. If we find any precipitation on the side or bottom of the bottle or the solution is opaque, not transparent, the solution cannot be used.

Do not place into the water the whole amount of the material soluble at a given temperature because excess amount can crystallize as the temperature decreases. We especially have to consider the solubility of each nutrient (Figure 4.) when mixing several salts because solubility inside the mixture changes.

Do not add phosphorous acid to the water containing calcium, manganese and iron in order to avoid precipitation.

Never mix acid or acidic fertilizer with compounds containing chlorine. It is even dangerous to store such compounds in the same room.

Never add the water into the acid because it can indicate thermal reaction and the water vapour can splash the acid. Use of protective equipment is compulsory!

For safety reasons only add the amount of compounds sufficient for the treatment of one irrigation cycle into the dissolving tank. This way we can prevent overdose.

When we continuously use chemicals of different quality and quantity, it is suggested to use separate pumps. This way we can prevent failures of assembly and portion adjustments.

Installation of the equipments should allow easy cleaning, rinsing. The moving parts of the pumps have to be cleaned after each use because salt molecules formed by drying can damage insulation when left inside.

To select the connection point of the pumps we should consider the following. If the connection is before the filter, we can separate any pollutant, which enters the system. If the automatic filtering system is installed, the chemical may pollute the environment. In this case the type of the automatics has to be chosen so that it stops adding the chemical during back flushing. When the nutrient injector allows it, we should filter the solution first and then it can even be connected below the filter.

In order to define the timing of fertigation within one irrigation cycle we can use two methods. One is to keep adding chemicals during the whole irrigation. This method includes continuous input of daily small amounts. In this case the equipment is installed and cannot be removed, only one type of plant occurs in the area. According to the second method we only add chemicals into the system in the second and third quarter of the irrigation period, which allows clean water rinsing of the main lines. This method is applied when different plant species occur in the same area or the chemical is added periodically including some concentrated portions.

To judge the uniformity of fertigation we need to know the stability of water output of the Queen Gil irrigation system, the required minimum is 90%. The stability of fertilizer output depends on the water distribution.

The fluctuation of the nutrient solution concentration is influenced by three factors:

- The solution is not correct in the tank of the mother solution, the added fertilizer only dissolves partially.
- Fluctuations of the fertilizer feeding pump performance during operation. The cause of this fluctuation can vary by types; change of pressure can be the influencing factor for the pumps operated by irrigation water.
- Change of irrigation water amount during time. The reason may be the various lengths of the different periods, different height of the terrain or occasional water removal.

We have to choose carefully the materials of the irrigation system elements when adding nutrient solution. All installed parts have to be resistant to the dissolving, oxidizing effect of different chemicals. Any form of copper induces corrosion of aluminium, the phosphor and ammonia damages bronze parts.

Safety elements have to be built into the system to prevent backflow of chemicals into the dwell, input without adding water and runoff.

Examples of fertilizer input using different types of injectors

The plant to be watered is paprika in a stage following fruit formation; the fertilizer to be added is MEGASOL pink, 30 kg/ha daily. Irrigation water demand is 5 mm/ha/day equals 50 m^3, duration of watering is 1 hour. Solubility of the fertilizer is 490 g/l (0.49 kg/l) water at 20 °C but to be certain only 390 g is dissolved.

a. Type of the nutrient injector is AMIAD 4-01.

1. Required water amount to dissolve the fertilizer: 30 kg /0.39 kg = 77 l.
2. Setting the nutrient injector, stroke number per 30 seconds: 77/4 = 19.

From the flow diagram presented in the instruction manual of the nutrient injector we can see that this stroke number requires 3.5 bar pressure and that amount is pumped into the main line in 1 hour. The displacement volume is 33 cm^3, the amount of powering water is three times greater than the amount of nutrient solution input.

b. Type of the nutrient injector is T.M.B. WP-60.

1. Required water amount to dissolve the fertilizer: 30 kg /0.39 kg = 77 l.
2. Setting the nutrient injector and defining the stroke number required can be completed by the flow diagram of the instruction manual, for the input of the above amount one stroke should take 12 seconds. The volume of one stroke is 250 cm^3, the amount of powering water is twice as much as the amount of nutrient solution input.

c. Type of the nutrient injector is Dosatron 16, 5 m^3/h.

The capacity of this circular nutrient injector is 5 m^3/h, therefore it cannot be built into the main drain. We have to construct a by-pass with a water flow of 20 m^3/h. The feeding %= 77/5000= 0.015.

d. Type of the nutrient injector is Venturi-tube

When the Venturi-tube is built into the by-pass, close the main line and set the concentration of the solution treatment according to the values listed in the table.

3.4. Measuring the characteristics of nutrient solutions

3.4.1. Measuring the pH

Figure 5.: manual pH measurement

There are two methods to use for measuring pH. One is the colour change of liquid or sponge tape reagents and the other is the use of electronic instruments.

The use of reagents seems to be easy and inexpensive but accuracy and reliability is not sufficient. Exact reading is difficult to accomplish, accuracy is not better than 0.5 pH when the measuring range is wide. When working with a type of narrow scale it is likely that the solution will be out of the measuring range.

The manual electronic measuring gauges are normally equipped with a glass electrode filled with gel, which allows about 2 years of operation.

We should consider the following requirements for choosing the right type:

- Measuring scale is pH of 2-12, accuracy is 0.2 pH and resolution of display should be 0.1.
- Calibration should be possible in at least 2 points (pH 4 and 7).
- The probe should be semitransparent glass, filled with gel.
- Batteries should provide the electric voltage, it is suggested that the instrument turns off after couple minutes of standby. Accuracy can be increased if the instrument shows low battery voltage.

During the operation we should consider the following. After dipping it into the solution wait till the displayed value stabilizes especially when we use temperature compensation. Always keep the glass electrode clean and in a humid environment. Wash the instrument in clean water after each measurement. If we do not use the instrument for 1-2 months, recalibrate it before application. Protect the instrument from strong heat and frost.

3.4.2. Measuring conductivity

The amount of dissolved salts in water can be expressed in several ways. Generally we use electrical conductivity (EC), measured in dS/m, mS/cm or μS/cm (1 mS/cm=1000 μS/cm). Measurements can be also expressed in ppm or g/l. The displayed values do not show the quantity or ratio of the different dissolved salts.

When selecting the instrument we should consider the following.

- Measuring scale of the instrument should be wider than the expected values of the greenhouse of 0.5-4 mS/cm, accuracy should be minimum 2 %.
- The instrument should provide a calibration option and the required test solution.
- The instrument should provide an automatic temperature compensation option. The temperature measurements may have a deviation of ± 50 %, this data is almost impossible to use. It is better to place the temperature detector outside the housing, in a metal case, which speeds up the stabilization of the displayed values.
- Batteries should provide the electric voltage, it is suggested that the instrument turns off after couple minutes of standby. Accuracy can be increased if the instrument shows low battery voltage.

During the operation we should consider the following: after each use wash the instrument in clean water. Regularly dip the instrument into an acetic acid with a concentration of 10% in order to dissolve the occasional salt precipitation. Do not use more concentrated acid or mechanical cleaning.

4. Irrigation system components

4.1. Water intake

Based on practical experiences when planning an irrigation plant the required and utilisable water has to be available with an 80% of security. Origin of water can be underground water, artificial channels or natural rivers, lake or sewage water.

Underground water

The sources of water withdrawals are drilled wells (Figure 6.) or shallow wells removing water from the rich groundwater layers near the surface. To plan the irrigation water withdrawals we have to know the annual water table fluctuations, the depth of the ground water table, the possible water output of the well, the rate of withdrawal in case of continuous removal and the water quality. The rate of withdrawal by continuous removal can be defined by sinking a test well. The inaccurate measurement of this factor endangers the applicability of the irrigation system. It is possible that the steady water level inside the well allows the

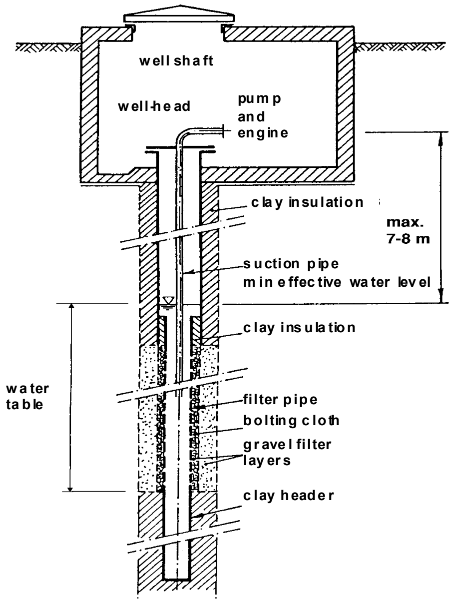


Figure 6.: structure of pipe well of large diameter

installation of surface pump. However the recharge of water is not sufficient for the compensation of the daily water removal, the water level becomes deeper. Because the diameter of the wells is normally small, there is no way to follow the water level with a diving pump. For the installation of submergible pumps the inner diameter should be at least 100 mm. When the water rises from layers deeper than 10 m under pressure, the depth of withdrawal has to be selected very carefully. In this case establishing other wells in the neighbourhood may result in unexpected situations.

The material of the wells can be steel, PVC, HPE pipe. Part of the pipe surface operates as a filter, total area of the holes should reach 20% of the total surface area. Choose the filtering apparatus according to the water table. When the particle size of the water table is mostly gravel or sandy gravel, the structure of the filter should be perforated or slotted; when the particles of the water layer are sand, gravel filter and screen cloth is required. The gravel filter should be at least 40-50 mm thick.

To protect the well we have to build a special, slow-release valve. If this valve is missing recharge is slow when starting the well, water is moved to the surface from the cave around the well. When water is removed from below the cave there is no more support left so the roof can fall and clog the water-bearing layer.

For shallow wells the fluctuation of water level shows regular cycles every year depending on the rainy season.

Surface water withdrawal

Water can be taken from a river, stream or lake. At the location of water withdrawal we have to define the required water supply, water levels and the capacity of water withdrawal for the plant. Water can be taken by stable plant or by floating pumping station. When the outlet is lower than the surface of the water source, use gates or siphons. The water removed can be transported by open drains or closed pipelines. The main drain and by-passes of the irrigation system are normally uncovered earth beds. To maintain the flow speed providing the expected water supply, we have to eradicate the waterweeds. The decaying plant remains first slow down the flow speed then fill up the drainpipes and make frequent dredging necessary. On the other hand the root system inhabiting the side of the ditch allows higher (1,8 m/s) flow speed than in the compacted earth bed (0,8 m/s) therefore it is useful to plant the side with grasses. If we want to avoid percolation losses and the resulting groundwater rise, we have to cover the bed. Up to 2/3 of the water running in uncovered beds can percolate. The continuity deficiencies of the insulation can significantly increase water losses. When the missing parts reach 2% of total surface, water losses are about third of that without any insulation. In the pipes with concrete lining the maximum permissible flow speed is 4 m/s. This speed means that the same amount of water can be carried inside the concrete pipe of a diameter 50% smaller than in the best clay-tile system.

The sprinkler-scheme pumping plant is a pumping station to provide the pressure required for the operation of the sprinkler system and the satisfaction of water demands. The mechanical equipment of the irrigation system and the sprinkler-scheme pumping plant operates as one functional unit, they depend on each other. The plant is automatically operated and controlled by the pressure of the delivery side and the utilized water supply. The periodical operation of the low-capacity booster pumps (Q=60 l/sec) allows water recharge of small water removal or dripping by the storage capacity of the discharge air chambers. The pressure drop followed by increased loss of water supply induces the continuous incidence of the main pumps (Q=200 l/sec) within a certain pressure range.

4.2. The pumps

The name of the pump already indicates pumping of some type of liquid. However the pump placed high above the water surface cannot transport water because the water is normally pumped into the pump-body by the created vacuum, where the pressure is low due to suction of the pump. The height to which a certain type of fluid can be forced by the air-pressure in ideal situation is called atmospheric pressure altitude, marked by B. For water this value can be maximum 10 m. The higher we are above sea level, the lower is the value of B. The actual pump lift further decreases due to pressure losses and cavitation. The practical pump lift does not exceed 7 m. Cavitation occurs when the pressure of the liquid decreases to the pressure of the saturated vapour on a given temperature (p=0,0238 bar on 20 °C) at that time water starts boiling creating vapour. Then the water shows discontinuity, the space is filled by the vapour of the liquid. Cavitation results in vibration, which damages the pump, lowers the rate of flow.

Mechanical characteristics of the pump include data and relations related to the technical properties. It is suggested to consider these data for the installation of the pumps.

The most important characteristics of pump operation:

- manometric pump lift (H; m),
- discharge per time unit (Q; l/s, l/min, l/h),
- capacity required for operation (P_{engine}, LE, kW),
- efficiency of the pump (η),
- maximum suction capacity (H_{smk}; m),
- and the revolution of the pump (n).

The characteristic of the pump defines the relation of two attributes. The most important of which is the Q-H characteristic (Figure 7.), which describes the connection of the pump lift and liquid flow at the same speed. From the characteristic we can read how much Q_1 liquid is transported to the required height of H_1 per unit of time. We have to consider that the pump lift (H) is not equal to the pressure below the pump (Figure 8.). Commercially the water flow is normally expressed by free outflow therefore we always have to verify the capacity of the actual pump on the required pressure.

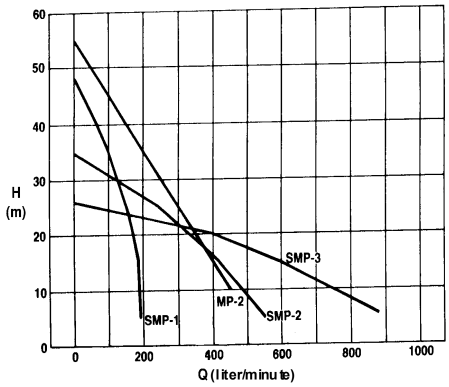


Figure 7.: Q-H characteristic of the centrifugal pump

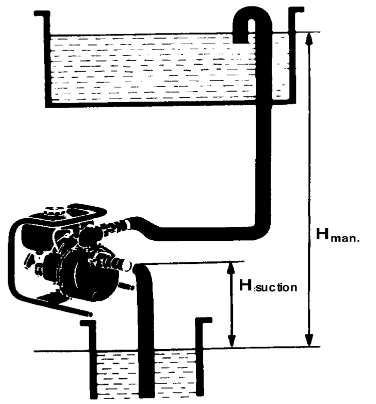


Figure 8.: pump lift and transporting height of the centrifugal pump

The majority of the pump operation failures occur from the incorrect installation of the suction pipe. The allowable range of the fluid flow speed should be 0.7-2.0 m/s and the pump lift should be as low as possible to prevent cavitation. Install a foot valve filter screen to the end of the suction pipe to ensure continuous fill of the suction pipe and prevent entrance of larger, solid contamination, which would damage the blade wheel of the pump. We should avoid placing the bend within a distance of 6xd and prevent the formation of air pockets before the pump. The suction capacity of the pump relates to the suction piece and it is loaded not only by the geodetic pump lift but also by the full loss of the suction pipe and pump well and by the feeding loss.

The pumps other than the self-suction pump should not be started when dry and without airing. The pump should not be operated when delivery side is closed or water level is low because the induced friction loss warms up the fluid inside the pump case, resulting in boiling. Upon stopping, close the delivery side before shutting the engine.

Two or more pumps can only be operated in series or parallel when operational characteristics (Q, H) are the same. When connected in series and discharge remains the same, the pump lift (H) is multiplied by the number of instruments installed. When connected parallel and pump lift remains the same, the discharge (Q) is multiplied by the number of instruments installed.

During pumping the pH of water should stay below 8, the floating or suspended contamination content below 5000 g/m^3, the temperature of water should be between 4-30 °C according to irrigation purposes and atmospheric temperature. The mechanical correction of irrigation water should be completed before entering the system, the chemical correction should happen before the last water withdrawal.

The aim is to install the pump into the centre of the area to decrease the pressure loss and the cost of pipe system. Do not decrease the suction or the lifting main drain that would result in the capacity loss of the pump. After decreasing, the pipe is not able to transport the amount of water given in the instruction manual although we paid for the capacity increase and for the operation.

The pump can be operated with electric engine, which has certain advantages over the internal-combustion-engine. If the electric network is well developed then the cost of investment is low, the conversion of electrical energy is efficient (85-90%), engine requires little maintenance, has a long life, it is available is several capacities, automating is easy. Operation is clean, silent; vibration is small. Disadvantages include fixed operating location, constant rotation and water transportation therefore we have to decrease the lifting main or use special type of electronics when consumption falls down. The engine operating from three phases is smaller, cheaper than the one-phase type of the same capacity. Advantages of the internal-combustion-engines include mobility and variability of the discharge amount depending on engine rotation.

There are several electric and fuel operated *centrifugal pumps* of different construction and manufacturer available commercially. Thickness of the pump case indicates the amount of water transportation, the ones with thicker case transport larger amount of water, larger diameters of the same engine capacity induce higher pressure. The pumps operated by power shaft (TLT) can be attached to a tractor when installed onto a wheeled vehicle. The cardan shaft provides the connection of the power shaft and the pump rod. By changing the gears we can adjust the optimum engine rotation from 540 rot/min to 1100 rot/min. Water supply can vary between 12-1020 m^3/h, manometric head between 7-105 m, required discharge between 13-97 LE.

The *submergible pump* is lowered into the well, water can be even lifted from a depth of 200 m. To improve actual lift, several centrifugal pumps, up to 32 pieces are connected in series. The pumps can be operated by underwater electric engine; the smallest diameter of this type is 3” requiring a well with an internal diameter of 100 mm. It is suggested to choose the best quality affordable because it is difficult to lift up the faulty unit and expensive to repair the electric engine. A new development of the submergible pump is the operation of the diving shaft from the surface. The diving shaft can be rotated by the tractor power take-off, belt-drive of internal-combustion-engine or electric engine; the smallest pump diameter is 4”. It is suggested to use where surface pumps cannot be used and electrical power is not available. A requirement of the drilling is that the well has to be perfectly vertical. The pump head is placed on a metal base with a concrete subbase, with the inside shaft it supports the pipes built on each other and the exhaust branch. The driving power can be angle drive, angle drive with accelerating gear or simple sliding connection for electronic engine. Cooling is provided by transition of the removed water. The length of pipe elements is 4 m, at the connections the driving shaft is held by the bearing.

The pumps of the lined dug wells have a special structure. The pump is located at the lower part, while the operating electric engine is at the top. Because of this construction water can be lifted from almost the bottom of the well; this extra amount can be significant considering the diameter of the well cylinders. The engine is cooled by the water running inside the skirt. At the one-phase electric engine the thermal release relay is built into the housing, which makes the operation very safe. In the lined dug wells it is possible to install inexpensive floating level switches, often built into the pump. The pumps installed with thermal relays and level switches operate very safely.

The *deep-pumping* (injector) pump is installed on the surface and capable of pumping water from a depth greater than 8 m. The pump head is equipped with a foot valve to allow the filling of the system with water. The injector is self-priming to some extent, which indicates that the pump located 2-3 m above the fluid surface is capable of starting the flow. This type of pump is tolerant to smaller contamination. It transports smaller amount of water than the centrifugal pump of the same engine capacity and requires a well larger in diameter, a submergible pump can be used instead.

4.3. Pipelines and accessories

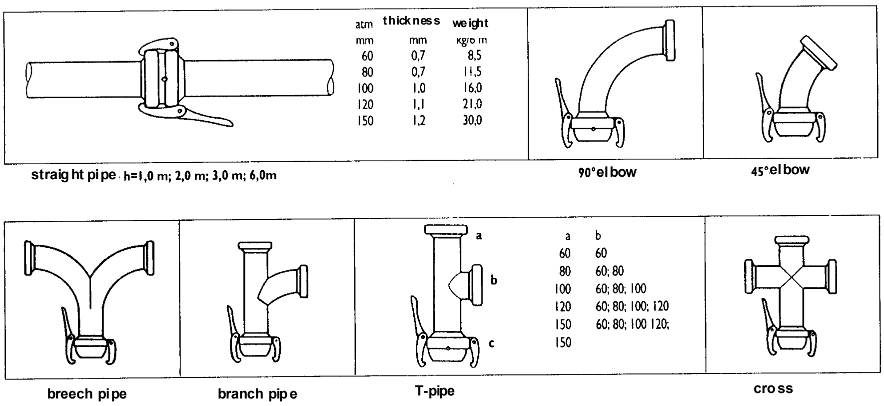
The *aluminium pipes* are not heavy, easy to install but can only be used above water without surface protection, chemicals induce corrosion.

The *steel pipes* are widely used in places where water discharge pipes are only installed temporarily. The outside surface always has to be treated against corrosion, which is done by hot-dip galvanising. The diameters in use are 60, 80, 100, 120, 150 mm.

The metal pipes are generally used to construct surface discharge lines, where the pipe sections are connected with clipper connectors sealed by rubber rings. This connections allows low angle direction change, follow up of surface roughness. Different types of the modules (Figure 9.) are available, e.g. the 90°, 45° elbow, breech and T pipes, diffusers and reducing pieces can be installed. They are stored in stacks so that the clamp female (F) is followed by the male (M) and the clamps of larger diameter hang below the row of pipes beneath turned by 90°. If the pipes are stacked facing one direction, we need to place at least three spacers above each other. This way we can prevent deformation of the pipes during storage.

The pressure loss of the metal pipes is greater than of the plastic ones because of the roughness of their surface (surface roughness value for the Hazen-Williams formula C=100) therefore we have to increase the value of Figure 10. by about 20%.

Construction of plastic, high-density polyethylene (MPE) pipes is becoming more and more common. This spreading is due to the low cost, easy handling and tolerance to corrosion. Because it is manufactured into long rolls, only a few connection parts are required for installations. They can be sawed, drilled easily with woodworking and metallurgic hand-tools. Can be applied for irrigation systems, well drilling.



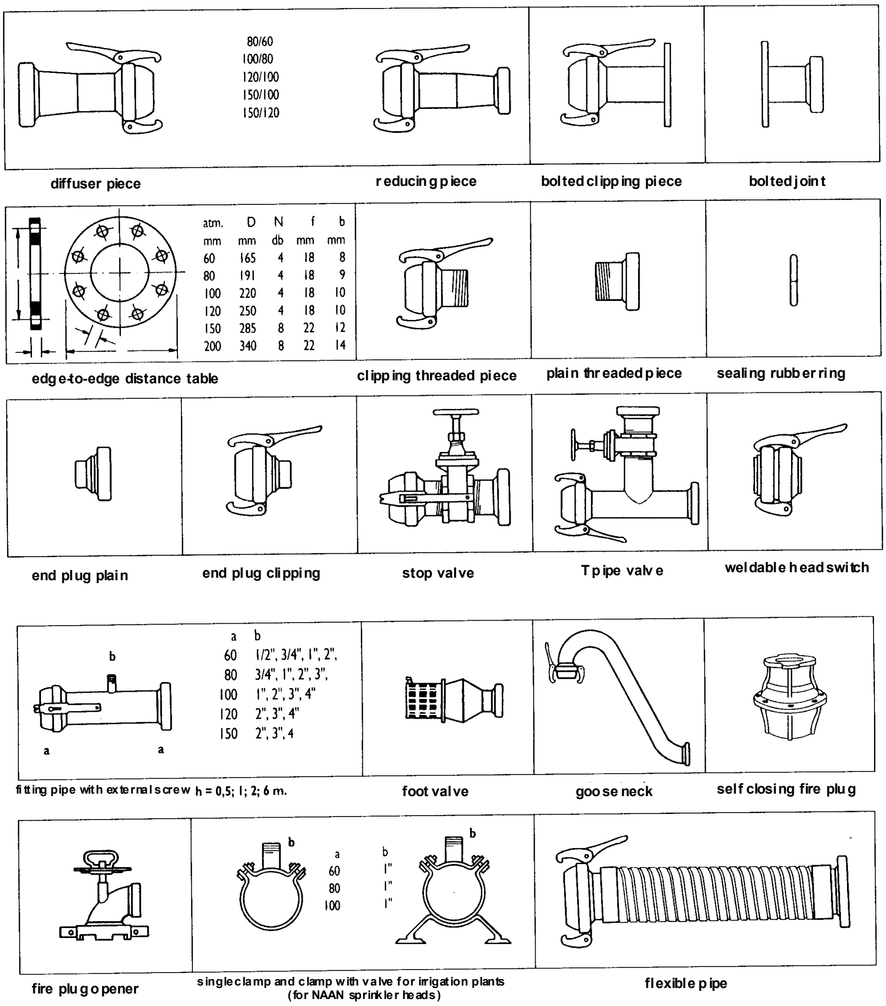


Figure 9.: elements of metal irrigation pipes

Because of the high chemical resistance, it can be used to transport the acid-, alkaline-, salt aqueous solutions. Input of different additives can develop resistance against the UV solar rays. When planting it subsurface we need to dig a narrow ditch, where the bottom can be rough. For the installation we should consider thermal expansion of 0,2 mm/m/°C therefore plant the pipe in curves or keep the temperature below 10 °C, when covered. The thermal expansion is 20 cm per 100 m for 10 °C temperature rise. The roughness of the surface is C=140.

They exist in several wall thickness, pressure stages. The pressure stages are 2, 5, 4, 6 and 10 bars on the temperature of 20 °C. At higher temperatures of the transported fluid the allowable pressure is lower. With increasing operation pressure, thickness of the pipe wall also increases along with the cost. Commercially the value of diameter always means external measurement, to calculate the current diameter we have to extract the thickness of the wall from this value. The pipes can be installed in a curve at a minimal bend radius of 20 x d. When buried underground we have to withhold any stone or sharp materials from touching the pipe. The mass of polyethylene per volume is 0,94 kg/dm^3.

In greenhouses, for permanent installation or for the transport of large amount (> 50 m^3/h) of water, we should use PVC base plastic pipes. It is not resistant chemically to chlorine, bromide, acetate, ketone. The bottom of the ditch should be even for subsurface installation, the pipe should be placed into a sand-bed, the elements and shapes into a concrete block of the appropriate size. The pipes are developed to be used in a covered environment therefore they do not have UV protection resulting in the discoloration of the surface. Normally they are sold in pieces of 3 or 5-6 m long, which can be fitted by a box joint or connected by gluing bonding units. The bare pipes can be extended by gluing with Vinilfix. They have a high notch sensitivity therefore we should not use threading. Thermal expansion is 0.08 mm/m/°C, which is 8 cm per 100 m for 10 °C temperature rise. The mass of PVC per volume is 1.4 kg/dm^3. Surface roughness is C=150.

Considering the rigidity of plastic pipes at low temperature, we should avoid placing the pipes below 5 °C. When installed permanently we have to place the pipes below the frost line. When installing pipes wider than 110 mm in diameter, we have to stabilise the pieces, slide-valves with a concrete support.

For planning and constructing the pipeline we should consider the pressure increase or loss caused by the water hammer. The same event occurs from the air blocked inside the pipe. Pipes of improper calibration and operation may break under load. The effect of water hammer can be decreased if we install gate valve instead of ball valves to prevent sudden pressure change. Due to their flexibility plastic pipes are more tolerant to sudden pressure change than the asbestos-cement ones.

The advantages of the layflat PVC tube with flexible walls are mobility, low cost, easy installation and better tolerance of field conditions. The tube is possible to cross with a vehicle without any kind of protecting device, which would not be possible for HPE or especially not for PVC tubes. To connect the irrigation pipes we need to use special pieces, these are available (Figure 16.).

Table 9.

Characteristics of HPE pipes of different diameters with the pressure of 6 bar

External diameter d (mm)	20	25	32	40	50	63	75	90	110
Col (")	1/2	3/4	1	5/4	6/4	2	10/4	3	4
Wall thickness (mm)	1.5	2	2.5	3.2	3.9	5	5.1	6.3	9
Mass (kg/m)	0.1	0.135	0.21	0.33	0.5	0.85	1.11	1.66	2.85

Plastic pipe fittings

Different types of fittings can be used for connection, junction.

The simplest one is the barbed fitting (Figure 10.). The structure of this fitting includes barbs of triangular profile on the skirt of the fitting. We can tighten the pipe onto these barbs using the flexibility of the material. This method is sufficient up to the pressure of 2 bar. To break the connection, cut the pipe in front of the fitting because this piece is elongated and could not be used again.

The special type of the barbed fitting is presented on Figure 11. Here we can see a colour slip ring moving on the conical surface of the body. When pulled, the ring moves towards the base of the cone increasing the diameter and cutting deep into the inner wall of the pipe. After the pulling force stops, the ring moves towards the tip of the skirt decreasing the diameter to prevent continuous tension of the pipe wall, which would result in dilatation and loosening of the connection.

With the barbed fitting and binding ring (Figure 12.) the pipe can be pressed onto the barbed cone, where the end nut secures the connection against expansion. First unscrew the nut from the form then press the tube onto the ribs to some extent but not fully to leave some movement for the tube to be engaged with the nut. This is especially important when the tube was not cut perpendicular to the axes. Finally screw on the nut. The disadvantage of this binding ring connection is that the forms cannot be used for each pressure range of the tubes. For example the form designed for a pressure of 10 bar does not provide a tight connection with the tube in the 6 bar pressure range, the sealing will not be efficient. The wall of the tubes larger than 40 mm in diameter is rigid, the tube can only be pressed on after warming up but even then the sealing is not always perfect. To break the connection cut the tube in front of the form and remove the rest of the tube from the barbs after unscrewing the end nut.

The use of the quick joint fittings (Figure 13.) is easy and secure when installed underground. In the greenhouse environment as the HPE tube warms up and looses from its rigidity, it might slip out from the joint. Here the use of binding ring is more secure. There is a wide range of products available to be used for different purposes. The versions of straight- and elbow connectors with external or internal threads, straight pipes and reducing pieces, threaded and socket T-pipes are available. The rubber bands of different contours between the end nut and the form provide the sealing, which can compensate small deformations of the tube.

Figure 10.: barbed fitting

Figure 11.: barbed fitting with slip ring

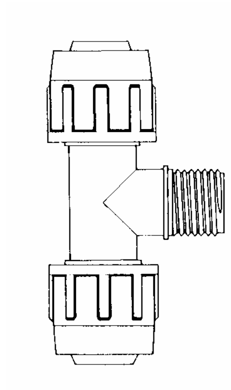
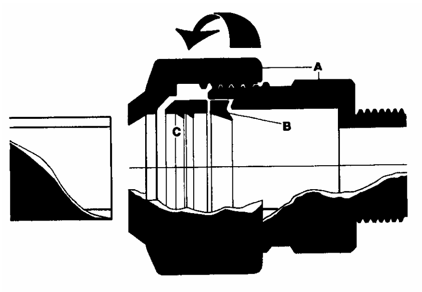


Figure 12.: barbed fitting with binding ring

To connect the LPE (e.g. QUEEN GIL type) tubes we can use special barrel nut fittings, where the cone has one supporting rib (Figure 15.).



A=barrel nut B=sealing ring C=binding ring

Figure 13.: Quick joint fitting

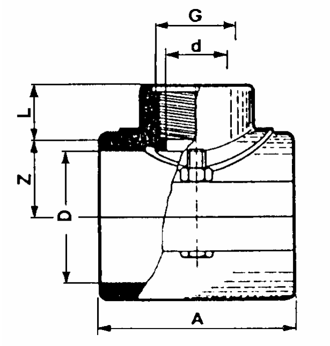


Figure 14.: clamp saddle

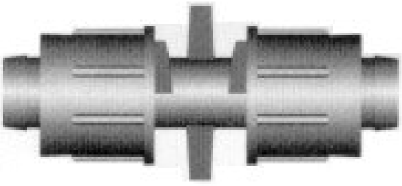


Figure 15.: fitting with binding nut

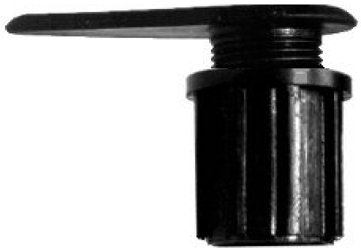


Figure 16.: Lauflat PVC tube fitting

Break the external edge of the tube end in 45°, besmear the sealing ring with a material soluble in water to improve sliding. This material can be potash soap or some type of a liquid grease solvent. Loosen the end nut, press down the tube till it stops then tighten the nut. To tighten the fitting, use some type of pliers. It is useful to mark the required length on the surface of the tube in advance because the tube will only reach the sealing ring if we do not loosen properly the end nut and the connection will not be stable enough. The fittings with sealing ring can be used up to 16 bar. To break the connection, unscrew the end nut totally from the form then prize open the fitting at the slot to move it. The connection is constructed on the external surface of the tube so its wall thickness does not affect the type to be used.

The socket or blunt-ended welding of the tubes requires special fittings and tools and expert knowledge. The connection of this method is stable, safe and closed therefore the disassembly of the system in the field is more difficult for a non-specialist, unauthorized person. It is suggested to use for the construction of connections in large numbers or for factory applications.

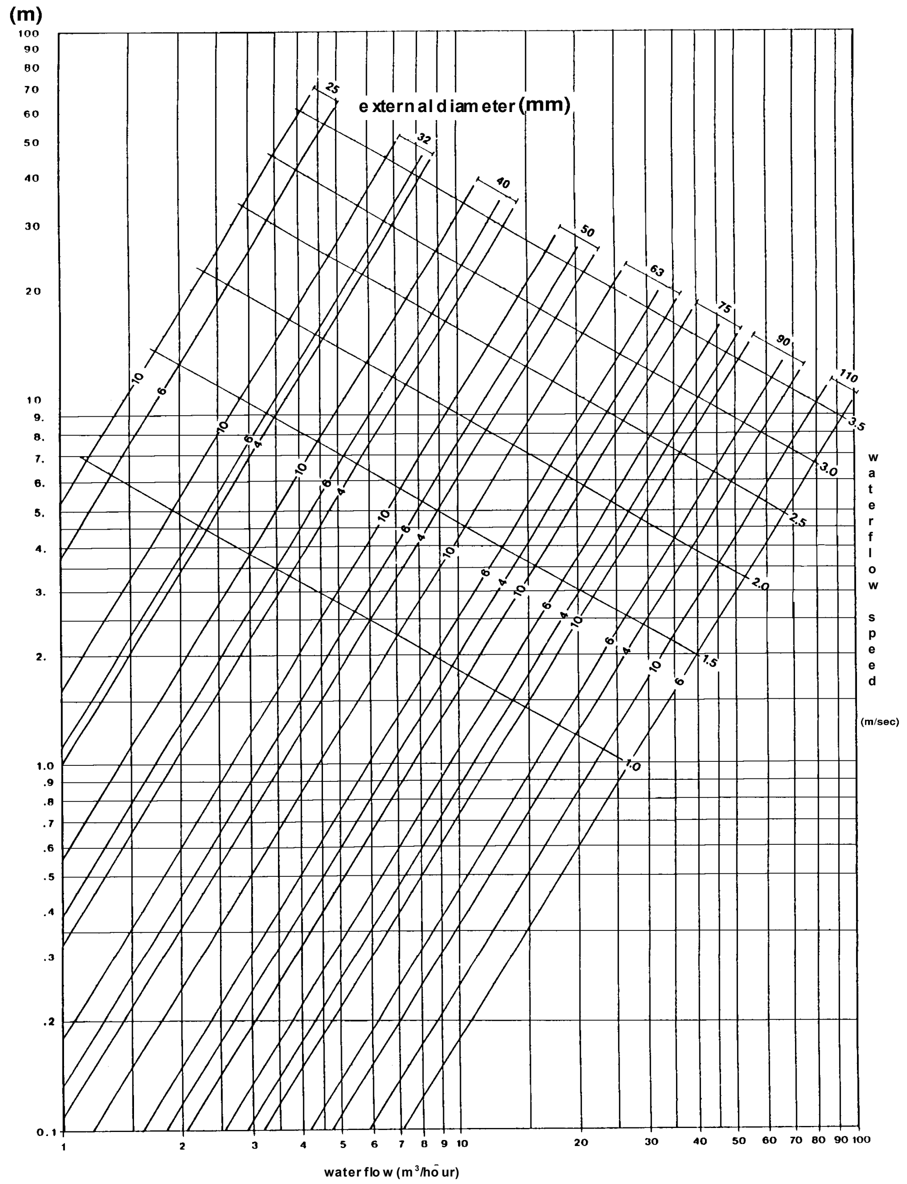
To construct the threaded connection we can use plastic nipple, box junction or mixed, male and female forms of various sizes (1/2"-3"). We can also apply the threaded elbow and T-pipes and threaded fittings, which allow connecting the pipes without chasing.

Try to avoid chasing onto the surface of plastic pipes. If we decide to chase threads onto a HPE tube of 10 bar pressure range than we can only apply a 6-bar-load.

Before matching the threads use a sealing paste, which prevents leaking but does not block future disassembly. We can also use a Teflon tape for sealing. It is forbidden to use hemp tow for sealing the plastic threaded forms because the hemp tow damages the shape of the threads therefore stability is lower and swelling can destruct the form. If we also install inflexible pieces e.g. copper valve into the system, it is likely that the connection loosens at this location when small twisting force is applied therefore it is suggested to use plastic pieces for the whole system.

Figure 17.

Water transport and pressure loss per 100 m of HPE tubes of different diameters and pressure ranges



The drilled forms or clamp saddles (Figure 14.) consist of two semicircular parts, which are located on the surface of the tube. They can be used to create branches. The threaded fittings are normally 1/2" smaller than the size of the tube. The material of the piece can be plastic or aluminium with one or two-sided starting option. The connection of the plastic types can be male or female. Screws or buckles can be used for fixing; O-ring or rubber plate provides sealing. For the installation tighten the fitting at the appropriate location then drill a hole into the tube. They can be used even on pipes under pressure but then we have to drill through a ball-and-socket and close the branch after the hole is ready.

It is possible to fasten the female nozzle clamp of the 50 mm fire hose with the 2" threaded fitting installed onto the end of the HPE tube, 63 mm in diameter.

Onto the HPE tubes 63 and 90 mm in diameter we can install aluminium mating pair of connectors sealed by rubber ring. During installation we should place a wooden fill inside the pair of nuts to prevent damaging the edge.

To reduce pressure losses at the tube connections we have to pay attention that the angle of connection should be the smallest possible; for constructing the branches breech pipes are preferred over the T-pipes to reduce the pressure loss to one third. The direction of water flow coming from the pump should depart from the general direction inside the pipes only by a small angle, we have to avoid sudden change in direction.

4.4. Filters

The filters are used to collect the physical contamination floating or drifting in the water. The diameter of the drip irrigation emitters is so small that we need fine filtering to prevent clogging.

Filtering of the water starts already at the intake. Filters of different diameters are installed to protect the pumps. To evaluate the need for filtering we need to know the diameter of the nozzles used. The fineness of the filter has to be selected so that the diameter of the physical particles transmitted should be smaller than the third of the nozzle diameter. For the organic materials (weeds, algae) the size of the particles transmitted by the filter should be smaller than the fifth of the nozzle diameter. Finer filtering is suggested because the pollutants can stick together, arch or the organic materials can pass through the holes in filaments while the size exceed the diameter of the nozzles.

Always clean the filters when a pressure loss exceeds the factory value by 0.2-0.5 bar. Automatic cleaning can be based on pressure loss when we measure pressure difference of the entry and emergence. When installing water meters, filtering is completed after the flow of a certain experimental amount. Filtering can be also started after an experimentally selected time period. When completing the procedure be careful not to let any pollutants into the pipe system. Install the filters right after the pump. When the water is very dirty, reduce the factory performance according to this level. Plan the capacity of all the filters except the centrifugal sand filter to at least

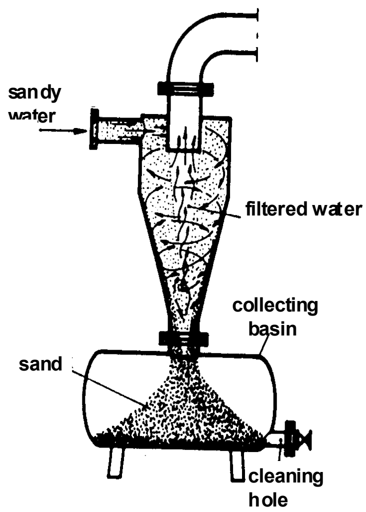


Figure 18.: centrifugal sand filter

20% over the expected water flow. If using different types of filters install the equipments in the following order after the pump: centrifugal sand filter, gravel filter, screen or disc filter.

The filters are not able to collect all the pollutants. The remaining particles are drifted by water then settle down as water speed decreases. To remove these particles we have to rinse out well the water pipes at the end of the season.

4.4.1. Centrifugal sand separators

This type of filter (Figure 18.) separates sand and particles heavier than the mass per volume of water (>1.5 kg/dm^3), it is not capable of separating organic materials. The water enters at the upper part of the cone and moves downwards in a circular motion. The actual centrifugal force presses the particles to the wall, which are collected in the bottom basin. The filter has to be constructed according to the amount of water flow and the characteristic particle size. The rule "the bigger the better" is not useful here because the speed, together with the efficiency of the filter decreases when equipment is oversized.

For water with high sand content we have to install a filter set for the particle size classes. Suggested to use for drilled wells when sand content exceeds 3 g/l. Suggested water flow speed is 1.5-5 m/s, pressure difference of the inlet and outlet is 0.5 bar. Experimental results suggest that this method can separate 98% of the sand and mud content, for microirrigation we need to use screen filter to separate the rest of the pollutants.

4.4.2. Gravel filter

Gravel filters (Figure 19.) gather pollutants inside the tanks on the surface of minerals and then remove the particles by water back-flow. Filtering is effective because cleaning is completed in three dimensions on the surface of the particles, which provides greater surface to adsorb pollutants. Filtering is not only controlled in a mechanical way, based on particle sizes but also by the surface potentials of the pollutants and filtering particles.

They complete the filtering of fine floating particles, like suspended organic materials, algae, silt fraction with particle sizes of 10-200 micron. This type is useful for utilising large amounts of fresh water and sewage. Purchasing is expensive and operation requires lots of care.

The filtering material can be sand, gravel or some artificial material; these require replacement in every 1-2 years. The filters may contain particles of similar or different sizes in the layers. Finer particles in thicker layers improve the effectiveness of filtering. Table 11. helps selecting the appropriate diameter of particles. The thickness of the layer should be between 40-100 cm. The fineness of filtering depends on the effective surface of the agent and the speed of the water flow. Application of finer particles reduces the chance for the development of larger cavities inside the filtering layer where the water would pass through without cleaning. Application of filtering layers of different particle sizes can result in the mixing of particles during washing therefore homogenous filtering materials are preferred. The upper layer should be replaced 1-6 times per year. At the end of the irrigation season deposited particles can be removed with acid treatment and water has to be removed from the filter.

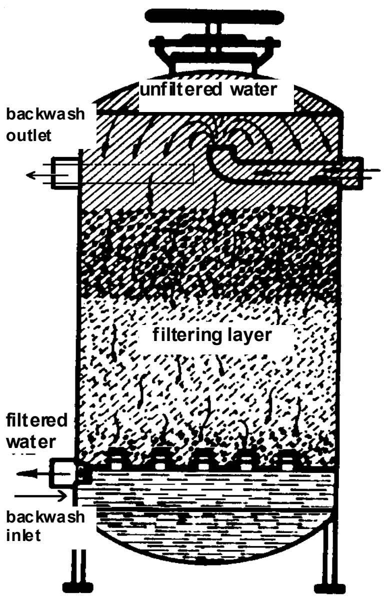


Figure 19.: gravel filter

Place a larger (12-20 mm) gathering gravel layer onto the bottom of the tank. This helps to prevent the clogging of filtering fungi and distributes water evenly under the full layer during washing. The suggested operating water flow is 24 and 61 m^3/h per 1 m^2 of tank diameter. The value should not exceed 49 m^3/h for the drip irrigation system. Because the capacity of filtering depends on the surface area it is suggested to use tanks of larger diameter. On the other hand we should consider that the tanks of larger diameter normally show lower tolerance to pressure. The amount of expected water flow depends on the rate of contamination and the frequency of washing.

The inner structure of the filter water basin is such that the rock touches the skirt at the bottom of the tank. The types with lamella filters can be damaged easily when cleaning is not sufficient. The stone layer saturated with pollutants does not allow water movement, water runs off from below the sheet, while pressure can even reach 4-6 bar above the stone layer. The inner surface of the good quality stone layers is slippery, covered by non-corrosive coating to prevent arching and then the whole pressure inside pushes the bottom sheet making it to break.

The water entering at the top of the tank is distributed upwards to prevent stirring of the filtering layer. The air valve at the top of the tank should degas the air stuck inside, which would make the entering water turbid and stir the filtering layer. To set the amount of backwash water we definitely need to install a valve onto the filter. The location and structure of the pipe draining the cleaning water should allow to visually define the purity of water output and to collect samples for defining the quantity of the output stone particles.

When irrigation is continuous we need to install at least two tanks. The cleaned water of one tank provides the washing water of the other. Because this time large amount of cleaning water runs from the system into the land and the filtering tank is open towards the irrigation system, the irrigation system do not receive the water portion required for operation. When three tanks are installed, washing one and operating the irrigation system at the same time is possible. During cleaning the water running fast upwards looses clogged filtering agent and carries away the settled pollutants. The effectiveness of the stone filter depends on regular washing.

The effectiveness of future cleaning depends on the installation and the first wash of the filtering agent. The particle sizes of filtering stones carried from the mine are normally not uniform, the smaller particles created by crushing are also included despite of the sieving before packaging. These smaller particles can be washed into the gaps of collecting surface and when stuck they reduce the effective surface area. To prevent the formation of the above process we need to consider the following:

1. Always buy pre-sieved and washed gravel.
2. Place the water collecting and filtering layers into the height defined by the manufacturer inside the tank.
3. Close all the valves.
4. When starting the water flow the amount of water running through should not exceed the amount for one tank.
5. Open the cleaning water valve of the first tank.
6. Slowly open the backwash valve of the first tank. Never start the process with a fast water flow because it can carry the gravel away. Open the valve gradually and take samples from the water running away. If the output particle size approaches the expected size category, the cleaning water flow cannot be further increased.
7. Close the backwash valve and repeat step 6. couple times. If we find that the set water flow is satisfactory, dismount the rotating disc of the valve to prevent accidental disadjustment.
8. Continue washing the other tanks paying special attention to the processes of point 6.

It is possible that we cannot provide the level of water flow, which would wash away the contamination. The reason for this can be:

1. The capacity of the inlet and outlet lines and the pump is not properly adjusted.
2. The washing tube is too long; it ascends creating a significant resistance.

The intervals of washing cycles can be controlled with differential barostat. In this case the system has to be adjusted so that the pressure difference of the inlet and outlet lines is between 0.5-1 bar. This means a 0.4-0.6 increase in the resistance of

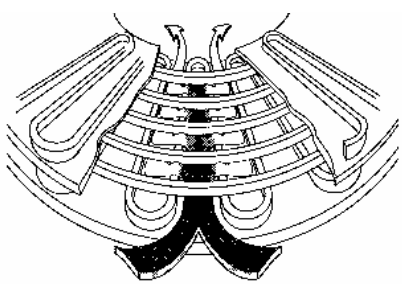


Figure 20.: SDF lamella disc

the filter induced by the deposited particles. The control should wash through the filter at least once a day independently from the pressure difference to reduce the chance of increasing microbe number. Adjust the duration of washing according to the analysis of water outflow. Verify this setting several times during the season because the quantity and species composition of organisms found in stagnant waters changes continuously.

The inner surface of the filters provides an excellent feeding ground for the different microbes. The deposited organic pollutants, the moist, warm environment creates ideal conditions for reproduction. The produced colonies connect and fix the particles reducing the effective filtering surface. In advanced stage the colonies split up, through the gaps the water runs without filtration. It is difficult to notice when such cavities are formed because the process is not accompanied by pressure change. Hard water taken from the well can also induce such cementation. The emitted carbon dioxide makes the calcium carbonate to precipitate and the particles of the filter to stick together. Such failures can be only noticed by analysing the cleaning water and the filtered water. To prevent these failures we should lift up the filtering layer and replace when acidic treatment is done or place new materials into the layer.

Table 11.

Fineness of the water filtering and the gravel used

Type of gravel	Average particle size (mm)	Fineness of filtering for a water flow of 35 m^3/h and filtering surface of 1 m^2 (mm)	(mesh)
Sand with round edges	1.3	0.21-0.16	70-90
	0.65	0.15-0.12	100-125
	0.5	0.11	130-140
Granite with sharp edges	1.5	0.15-0.11	100-140
	0.8	0.11-0.08	140-200
Sand with sharp edges	1.2	0.11	130-140
	0.7	0.1-0.08	150-200
	0.5	0.08-0.06	200-250

4.4.3. Screen filters

Screen filters are used to filter particles of sizes larger than the size of the holes.

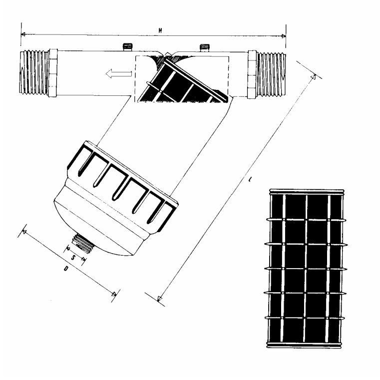


Figure 21.: screen filter

a. The filtering agent can be a screen (Figure 20.). The screen of fine plastic material may expand due to pressure rise, can be damaged easily during the cleaning therefore it is preferable to use stainless steel net. For the installation check the arrow on the side of the housing, which indicates the flow direction of the water. A guard bow is installed by the manufacturer on the entrance side in order to lower the load of the net.

Pay special attention to the cleaning, check the system regularly because the pressure decreases on the other side of the net when it is filled with pollutants. The force of the created pressure difference can deform the pump strainer, the filaments of the net can move away from each other, become thinner and finally break thus allowing the water to run through without filtration. This method can be used to clean the water of drilled wells containing *sand* pollutants.

The structure of the two ends of the pump strainer is not always the same therefore we have to pay attention to keep the right direction when reinstalling.

b. At the disc filters the fineness of filtering depends on the number and height of ribs on the lamella.

The new SDF type lamella filters (Figure 21.) have several advantages over the conventional barbed type. They have large filtering surface area, the pressure loss is small and they can collect larger amount of pollutants on the surface so the cleaning intervals can be left longer.

The characteristics of the lamella canisters: the structure allows the size of the holes to remain the same, the effective filtering surface is large (Figure 22.), the lamellas are easy to clean when pulled apart. The lamella filters are mainly used to clean waters of open surfaces containing *organic* pollutants. When cleaning, first loosen the lamellas then rinse the cartridge with pure water. Automatic cleaning is also available as described for the gravel filter. Although the initial cost is higher than of the screen filters but the structure allows that increasing input pressure due to the lack of cleaning does not harm the cartridge therefore we have to install this construction when possible.

For sealing the connections of the filters with plastic housing we should use Teflon tapes. The friction of the Teflon tape is low, the force required to screw the threads together is small. If we turn the elements till they stuck the fittings can break off. The water makes the hemp tow sealing to swell, induced forces can break the fittings or deform the threads therefore we should avoid application.

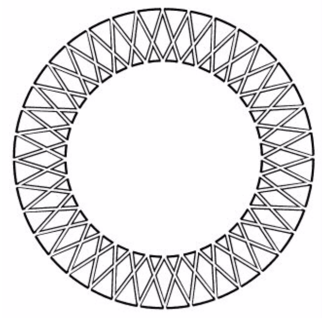


Figure 22.: grooved disc

Characteristics of the filters:

a. Size of the fitting threads connected to the water pipes. The fittings are normally 3/4”-4” in diameter, smaller filters have external threading, the larger ones may be equipped with flanged fitting.

b. Recommended water flow in m^3/h. The amount of water flow should be planned based on the capacity of the system and the pollution level of the water.

c. The size of the holes, measured in mesh size. The mesh size expresses how many holes are there for the length of 1 inch (25,4 mm) of the filtering surface. This means that the larger the mesh size, the thicker the cloth of the screen will be. Table 12. lists the colour sign of the fineness of pump strainers, lamellas. The colour sign is not standard, can vary for different manufacturers; it is useful to confirm the exact value upon purchasing.

Table 12.

Colour sign of sieve filters according to the fineness

Colour	grey	green	blue	white	azure	red	yello w	black	brown
mesh size	20	30	50	75	100	120	155	200	450
micron	800	500	300	200	160	130	100	80	22
mm	0.84	0.59	0.30	0.19	0.15	0.12	0.10	0.07	0.03

d. The size of the effective filtering surface, which normally equals 1/3 of the total surface area for screen filters. The effective filtering area should be at least eight times the diameter of the fitting tube.

e. The cleaning method, which may be manual, mechanical or automatic. Measure the pressure loss caused by collected pollutants regularly. When we measure a pressure loss higher than the manufacture value of the actual water flow clean the filter.

When storing during winter, carefully remove all the water otherwise freezing will crack filter housing.

4.5. The pressure regulator

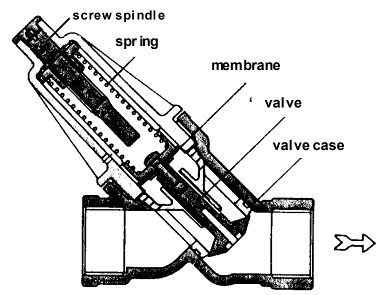


Figure 23.: pressure regulator

The pressure regulator (Figure 23.) is practically a hydraulic automata, which consists of a spring-loaded membranous control part and a valve-regulating unit. It is installed to prevent the pressure in the tube following the unit from increasing above a certain value. When in use and the system reaches a pre-set maximum pressure limit, it reduces the flow diameter automatically till the operational pressure becomes constant.

Irrigation is necessary to maintain constant pressure that is the only way to ensure constant water output. When several irrigation sections are applied, higher pressure is required inside the main line than at the outlets because of the different pressure losses and the possible elevation differences. In this case we have to install a pressure regulator for each irrigation section.

Generally 20% pressure change indicates 10-15% change in the water flow. This means that the operation of the system is sufficient when the deviation of the pressure is not larger than 20% in any part of the irrigation section. This value is the base for planning the irrigation systems. The irrigation systems of low intensity operate under the pressure of 4 bar.

The springs of the pressure regulators are manufactured in different colours, which indicate the maximum pressure allowed. The colour sign is not standard, it is possible that the yellow colour of one manufacturer indicates a pressure of 1.2 bar while 1.8 bar for another one. For some types of low capacity it is possible to change the maximum pressure by adjusting the stretch of the spring. By turning the screw spindle towards the + direction of the housing, the maximum pressure increases; towards the – direction the pressure decreases.

Install it into the system following the filter, the closest possible to the outlets paying attention to the flow direction marked on the side. The incoming pressure should be at least 0.5 bar higher than the expected pressure of the output. A minimum amount of water flow is required to make controlling possible, which value differs for the different valves; generally the minimum is 5% of the given capacity. Below this value the pressure-reducing valve does not operate, the incoming and outgoing pressure will be the same.

4.6. Equipment for inputting nutrient solutions and chemicals

A main part of the microirrigation system is the equipment supplying the nutrients. Operating the nutrient injector provides a nutrient supply in solution according to the plant needs. The injectors also play an important role in water treatment and in releasing fertilizers, soil conditioner materials.

During operation always pay attention to the safety, health and environmental requirements. When treating public water source, use backflow valve to prevent occasional backflow of solution caused by failure of control system or strong water hammer.

Drinking the treated water is also dangerous; the water source can be easily mistaken on the field.

The whole system has to be constructed from corrosion proof materials. The chemicals have to be carefully selected, perfectly dissolved and the reaction with each other and with the salt content of water has to be supervised. It is possible that one of the chemicals induces precipitation and thereby the clogging of sprinkler heads and drip irrigation parts. Some chemical reactions are slow and might not result in precipitations on the filter only in the consecutive parts.

When selecting the type of nutrient injector we have to consider the following factors.

1. The fertilizers used can be of solid or fluid state. We do not need a mixer to solute the liquid fertilizer.
2. The danger class of the materials used. The safety instructions are simpler when only fertilizers are used compared to that of acids, chlorine or insecticides.
3. The source of energy for injection. When electricity is not available, we can use the energy of irrigation water or internal-combustion engine.
4. The nutrient injector can be fixed or mobile.
5. The quantity of chemicals to be added. General rule is to add a ratio of 0,1-1,0% to the irrigation water.
6. Is it possible to mix the materials to output with each other or they should be separated into different tanks by type.

The change in the concentration of chemicals can be related to three main reasons:

1. Bad solubility or mixing in the container. Check the full dissolution of the solid fertilizers; apply automatic mixing to prevent deposition of particles.
2. The nutrient injector cannot maintain a constant rate of output. The reasons for this can vary by pump types.
    - The concentration of the solution continuously decreases in the dissolving tank used.
    - The capacity of water-powered pumps depends on the pressure of the network. When switching to a new irrigation section, the pressure conditions along with the rate of outflow change.
    - The uptake of the Venturi-tube also changes depending on the amount of water flow and water pressure.

- The filter of the suction pipe is getting clogged gradually and reduces the water flow through the pipe.

3. The water flow inside the irrigation system changes.
   - The length of the different irrigation sections varies.
   - The geodetic altitude of the different irrigation sections is not the same.
   - There is another type of water removal attached to the irrigation system temprarily (e.g. filling the container of a spraying machine)

Table 13. provides information on selecting the right nutrient injector.

Table 13.

Comparison of different nutrient solution feeding equipments

Characteristics	Dissolving tank	Venturi-tube	Pumps
Easy handling	yes	medium	difficult
Use solid fertilizer	yes	no	no
Use liquid fertilizer	yes	yes	yes
Water discharge	high	low	high
Concentration control	difficult	medium	easy
Quantity control	good	medium	good
Pressure loss	low	high	none
Automatic control	low	medium	simple
Price	low	medium	expensive

4.6.1. Dissolving tank

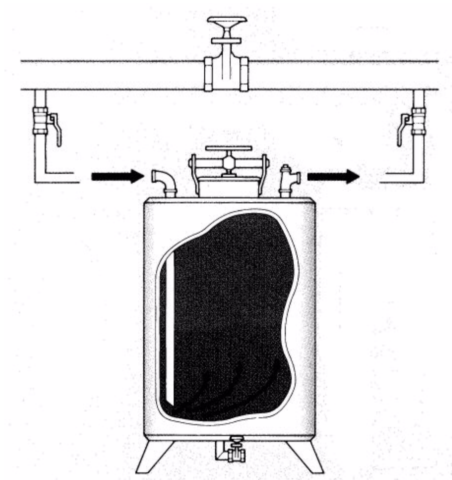


Figure 24.: dissolving tank

The operation of the dissolving tank (Figure 24.) is based on the application of the pressure-proof tank installed into the by-pass of the irrigation system. By slowly closing the cock installed into the main pipe, part of the water will run through the tank and dissolves, dilutes and transports the materials placed inside. The concentration inside the tank continuously decreases. If we use liquid fertilizer, the amount of water flow should be about four times the volume of the tank used to transport all the materials. For solid fertilizer the amount of water flow should be tenfold the volume of the tank. The pressure difference of the input and output tubes should be 0.1-0.5 bar.

The optimum size should be defined upon practical experiences. It is suggested to use a tank size, which would support the whole amount of water required for one watering during the irrigation period. If this is not possible we can either stop the watering at a certain point or make the tank independent from the pipe during refilling.

The advantages of this system are low price and easy handling. We do not need an external energy source, the system is not sensitive to fluctuations of pressure. Disadvantage is the continuous fluctuation of concentration during output. Therefore it cannot be used for continuous water treatment. For more irrigation periods we have to refill the tank therefore the operation cannot be automated.

The tank is under the same pressure as the network, the walls and closing valves should be planned accordingly.

4.6.2. Venturi-tube

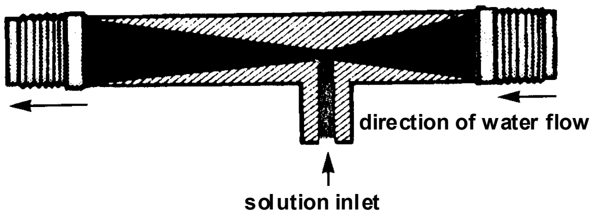


Figure 25.: Venturi-tube

When the diameter of a tube is contracted, the flow rate becomes faster and sucks in the solution through a connected tube. The amount of solution taken can be adjusted by the rate of water flow, within the limits of the capacity of the Venturi-tube (Figure 25.). The advantage is that there is no need for external energy source, no moving parts are used. The disadvantage is the high pressure-loss, up to 40%. Under variable pressure conditions the exact adjustment of injection is difficult. There is a mechanical detector attached to some types indicating the actual suction force inside the by-pass, this helps to set the operation range. Capacity varies between 5-1950 l/h. Connected parts can be 3/4”-2” in size, install it in front of the screen or disc filter.

Always install a strainer to the end of the suction pipe and clean it regularly. The effective surface of the strainer should be placed couple centimetres far from the bottom of the storing container. That way we can prevent the suction of the deposits, which would result in clogging. Installation of water meters and hydraulic valves can automate its operation.

The Venturi-tube can be used to increase the dissolved oxygen content of the water when the suction pipe outlet is in the air. The oxygen will be bond inside the water of high-speed turbulence and as exiting through the feeding elements it improves the aeration of the roots.

Figure 26. shows two ways of connecting the Venturi-tube.

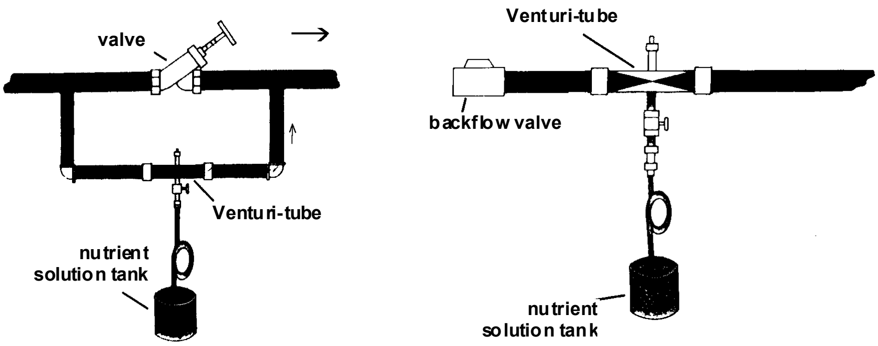


Figure 26.: Two methods for connecting the Ventori-tube to the drainage network

4.6.3. Injection systems

Using the energy of the irrigation water

They pump the solution into the system using the energy of the irrigation water; therefore external energy source is not required. The number of portions with fixed volume depends strictly on the pressure of water, feeding can be controlled effectively. Automation can be done by installing fluid-meters and valves. The required pressure for operation is 0.5-1.5 bars. The operation is not influenced by the amount of water flow in the transporting pipe but by its pressure, allowing the feeding to be adjusted flexibly.

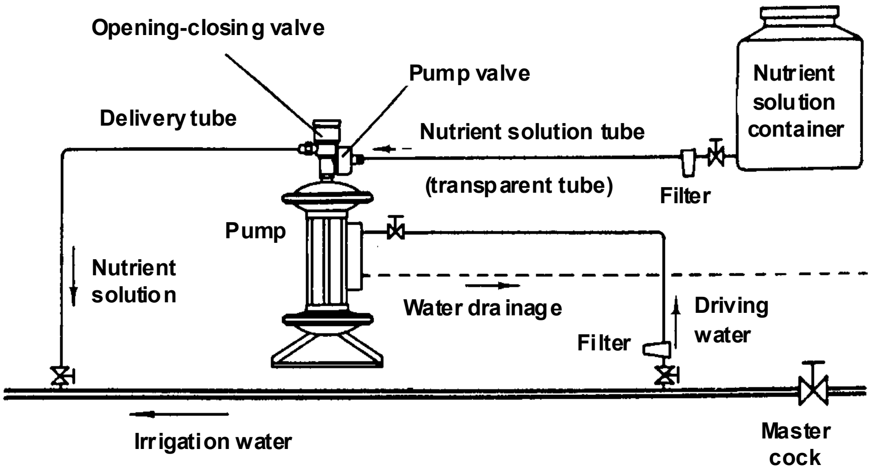


Figure 27: Installing the T.M.B. membrane pump into the irrigation network

They are installed onto the main lines, the closest possible to the pump, where the pressure is the highest inside the system. Create two branches with closing valves of the right size at least 30 cm far from each other. The one closer to the pump will be the water tube carrying the water necessary for operation; the solution runs through the farther one into the drainpipe. We have to ensure the storage and draining of the water outlet. By choking the discharge line we can control the amount of nutrient solution. By closing the valve the number of strokes along with the volume of the solution input decreases. Capacity can reach 1900 l/h.

Some types of injectors, built into the system use the pressure drop of the output side to operate and do not release water. Depending on the type of utilization this characteristic can provide significant advantages. They require much higher water flow for operation than the methods described previously, feeding also depends on this value.

Rinse the pumps with pure water after each use because the salt crystals can damage sealing and valves when dry out.

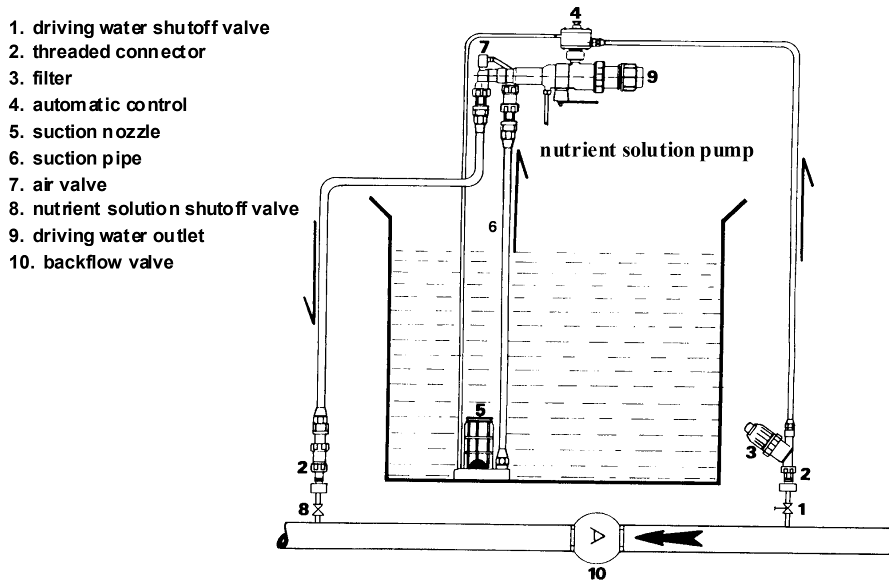


Figure 28.: Installation plan of the AMIAD 4-01 type nutrient injector

Figure 27. represents the installation of the membrane pump. There are several variations available according to maximum capacity, water flow capacity can be: 3-50 l/h, 15-250 l/h, 50-600 l/h and 100-1200 l/h. The required water amount for powering is twice the amount of the injected solution. The pump is operated by downflow, the nutrient solution level has to be higher than the height of the control valve.

Figure 28. shows the installation plan of a linear engine type pump. When all the solution is removed from the tank, it stops automatically. Feeding can be stopped manually, as well or the stroke number can be set electronically. The amount of water for powering should be three times the amount of input solution. One unit can transport maximum 320 l/h solution, this amount can be increased by building a control unit and several pumps together. The self-priming and downflow types are available. Connections are easy to open which allows easy handling not only in the factory but also on the field.

In the MSR type flow-through nutrient injector (Figure 29.) a moving membrane transports the nutrient solution, which resists wearing better than the sealing of the piston. Several suction heads can be installed transporting as much as three different solutions into the system. It pumps up the water from a depth of maximum 3m, amount of water flow is 0,03-50 m^3/h depending on size, and the input ratio can be set between 1:100 and 1:10000.

There are several capacities commercially available of the through-pass injector, showed on Figure 30. In the largest capacity, 400 l/h solution can be transported with the water-flow of 20 m^3.

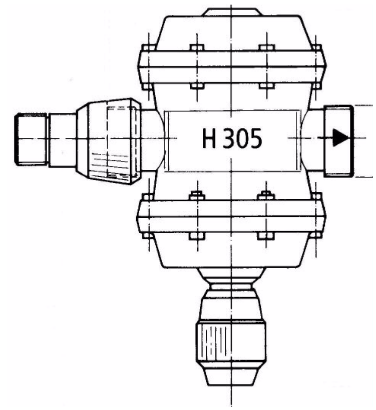


Figure 29.: MSR type flow-through nutrient injector

Using external energy source

A separate booster can also transport the solutions into the pipe, feeding can be very accurate depending on the method used. Electricity, internal combustion engine or power shaft of the tractor can be used for the operation. The pump driven by electricity is easy to be automated. During the system run we have to consider that the operation of the irrigation and nutrient feeding system is independent from each other. When the irrigation water flow stops, the transport of nutrient solutions may continue providing a solution of maximum concentration for the roots. Using a water-flow meter for signalling prevents this problem. They are normally used in greenhouses. The amount of transported fluids is optional.

4.7. Water meters

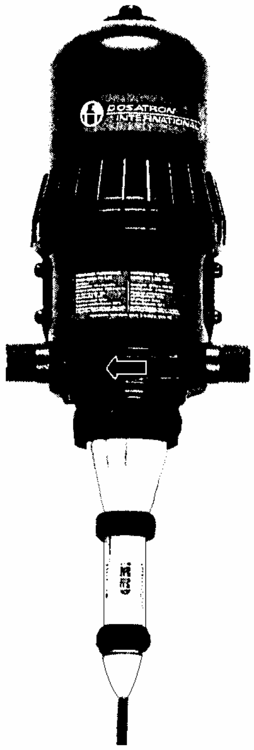


Figure 30.: Dosatron type through-pass nutrient feeder

They are used to show the amount of water, to transmit the flow of planned water amount then close the drainpipe and to emit an impulse signal for controlling the solution injector or for cleaning the automatic filter.

Mechanical dial indicator

After installation we receive accurate data of the plant water demand, we can plan and verify irrigation rotation. We can conclude the failures of the system. Decreasing water utilization may indicate clogging of the outlets; increasing water flow may be the sign of damaged network.

In modern meters magnetic interference is used for signalling, the display does not have a direct connection with the solution. A different meter is used for each tube diameter so the water amount can be measured on the widest range here, from 30 l/h up to 1000 m^3/h. The smallest connection size is 1/2" the largest is 12". The accuracy is ± 2 %.

The automation, computer techniques and the need for easier interpretation require the transformation of the values to electric signal. Different types of transducers are used to complete this process. The Reed-relay opens up and closes by the rotating movement of the nearby magnet. The magnet can be installed onto the fan-wheels or partial-flow indicators of the water-flow gauge. The smallest measurable amount 1 l. The use of the *photodiode* allows higher resolution, already indicates the flow of 0,005 l. The transducer is installed onto the leak indicator of the water-flow gauge. The signal is then transformed by different analysing and display electronics to allow readings or system control.

Meters using other methods

By contracting the diameter of the water discharge pipe the speed of the fluid increases, a pressure difference occurs between the contraction and the emitter, which indicates the volume flow to some extent. It cannot be measured under slow speed.

There are no moving parts in the ultrasonic meter, it is accurate, easy to install, can be operated by electricity.

4.8. Automation

Mechanical water-flow meter

It allows to output a certain preset water amount and to close it afterwards. The amount of water flow is measured with an accuracy of ± 4 % therefore the pressure change does not affect the output of the required water amount. Some types also indicate the total amount of water consumption. We have to adjust the amount to be output on the scale of the meter. During the operation the disc turns and shows the remaining amount, which can be modified any time. When it reaches the set value the water-flow is closed.

When the diameter of the tube is larger than 1", the water-flow meter controls a hydraulic valve (Figure 30.). The structure of the valve is simple; it utilizes the pressure of the water running in the tube for operation. The operation is presented on Figure 31. The figure shows the position of moving parts in opened and closed stage. Number one marks the upper part of the controlling chamber. If we input water here from the side of the inlet, it pushes the valve disc to the valve face with the help of the rod (number 3) thus closing it, because the surface of the membrane (number 2) is larger than of the valve disc (number 4.). If we let the water to the surface or to the side of the outlet, the pressure of the water opens the valve from the side of the inlet. The valve can be normally closed (N.C.) when the pressure is constant in the upper part (number 1.) of the control chamber or normally opened (N.O.) when the pressure is constant in the lower part (number 5.). They can be useful for the cleaning of filters, the control of irrigation periods, in greenhouses or in water cultural systems.

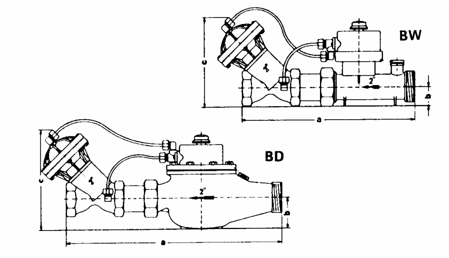


Figure 30.: water-flow meter

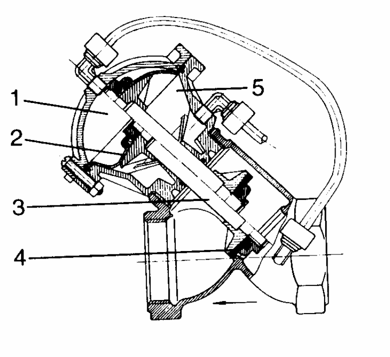


Figure 31.: hydraulic valve

Time control

It ensures the portioning of water between preset dates. The operation does not depend on the amount of water flow therefore portioning is not accurate, deviation can be as much as 30%. Advantages are easy operation and possibility for automation. This can be especially important when we use irrigation periods to compensate the capacity of the water source and we switch to the irrigation of the next period after the output of the portion.

It is possible to electronically control 1, 4, 6, 8 or more pieces of valves, normally closed. The electric source of the control with 1 and 4 valves can be 1 battery of 9 V. We can also start the electric pump for the types using external power supply, then the valves are controlled by 24 V AC power. The time of irrigation can be defined by calendar days or by certain time periods e.g. for every two days. It is also possible to start irrigation several times a day. Under field conditions the rain- or moisture detectors are important parts of the system, they cancel the actual cycle when the water supply of the soil is sufficient. These detectors can be of different mechanisms. For the installation it is very important to keep the circuit closed in normal position. When connected to the circuit of the control they do not affect the set program till the detector becomes wet. They can be applied for one valve of for a group of valves. The detector should be placed to a depth at 2/3 of the root length. In this case smaller amount of rainfall do not affect the control. The method above can only be used for valves, where a continuous magnetic field ensures open position but the lack of this field sets back the valve to normal position. To save energy, for the DC control opening-closing can be performed by reversing the polarity of the cable current. When we break the circuit at open valve position, the valve does not close.

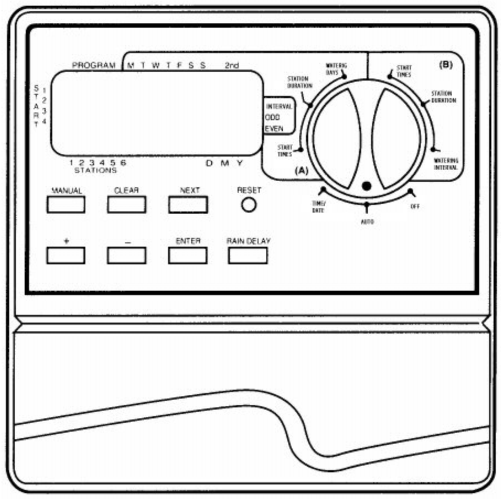


Figure 32.: electronic control

Electronic system control

The valves are important parts of the system. They are manufactured in normally closed (N.C.) and normally open (N.O.) forms. The water is directed towards the control chamber of the valve by electronic switches (driven by solenoid or DC differential engine). The solenoid types are linear electronic engines, can be operated by AC or DC (latch) of 12-24 V. Operation by manual override is always possible. It is advisable for the control to have a water budget program. Then with only one setting we can increase or decrease the operation time of all the valves according tot the daily weather conditions. The control unit presented in Figure 32. is modern, can be programmed with push buttons, the set values are presented on a liquid crystal display.

It is suggested to build rain- or moisture detectors into each system. The soil moisture content can be measured by tensiometer; the meter has a special structure including adjustment options and microswitch. The electronic controls can receive the signals of the detectors in two ways. The most common method is that the sensors are normally closed and electric current runs in between the fasteners. In this case the detector is connected into the common line of the circuit of electrohydraulic valves. The connection is possible at any part along the cable. During rainfall the hygroscopic sensor of the detector bloats and opens the circuit. Then the control voltage of the automata does not reach the valves, they remain closed.

The newer generations of controllers receive the signal of the rain- or moisture detectors on the main electronic board, where the closed stage of the detector breaks the operation of the control.

Computer-based system control

Complex systems can be built with the modern detectors, valves and computer techniques. During plant development we can adjust the treatments to the changes of the environment. We can pre-determine each step of this treatment, record the causes and results for future analyses. Modern systems have a structure, which allows the input of commands through the monitor or the automatic control through built-in algorithms. We can also build up a security system of variable parametric adjustments. At the same time we can follow up the actual state of the system (e.g. operating pumps, irrigation periods) and record data (e.g. amount of water output per rotations and total amount). The farther irrigation sections can be controlled through cable or by radio signals.

The detectors in use can measure the characteristics of the atmosphere (solar energy, air temperature, CO_2 and relative humidity, wind speed, amount of rainfall), act as transducers to control and verify the operation of the system (pressure- and water flow meters, tensiometers) or control the nutrient supplies (chemical reaction-, electric conductivity- and water flow meters).

The detector signals and the operation of valves can control several functions:

- Operation of pump plants, starting and shutting down irrigation periods, automating the backwash of the filters.
- Input of nutrients and water treating materials.
- Water and nutrient supply, climatic control of greenhouses.

4.9. Other network elements

The *hydrants* are water outlets on the field along the main lines wi th a valve shutter. They allow the connection of one or more irrigation lines at the same time. Water-flow meters, pressure- and water-flow adjustment valves can be mounted.

The *shut-off valves* control the water flow. Normally they are either closed or open but they can control the amount of water flow when turned. They are available in several constructions, it is suggested to install slide valves to prevent water hammer. If the shut-off element is installed onto the end of the tube, it is called the cock.

The *safety valve* prevents water hammer to cause damages. It should be installed to the deepest part of the drainpipe.

The *air release/inlet valves* discharge the air entering the delivery pipe under pressure or let in the air when draining the pipe or in the depression phase of the water hammer. The air bell entering the pipe reduces the flow diameter, the amount of water flow and improves the chance of water impact. The valve should be installed into the highest part of the system. The size of the valve has to be defined exactly. In systems of low pressure (<0,3 bar) automatic valves should have big opening, while in high-pressure systems automatic valves of smaller openings are needed.

The *backflow prevention valves* ensure the monodirectional flow of the water. They are fully automated in operation; the water pressure provides the energy for closing. They should be installed behind the pumps or at the connections to communal water network but the foot valve of the pumps also belongs to this type. For the addition of chemicals they use of these valves is necessary. In that case they have to be installed into the system before the input location of the chemicals to prevent pollution of the water source. Install a type to be closed by spring-load into the feeding pipe to prevent unwanted dripping from the feeding pipe.

The *adjusting valves* are installed to keep the pressure and flow-through in the main drain constant. The operation is automatic but the limiting values have to be pre-set.

The *drain valves* are used to derive the network, to prevent the damaging effect of winter frost. When the pressure inside the network falls below 0.5 bar, the inner spring releases the cover-plate from the valve seat to let out the water. They always have to be installed into the low parts of the system. A special application is for rinsing of the drip irrigation system lateral.

5. The microirrigation

The irrigation systems, commonly referred to as microirrigation apply very small amounts of water (< 500 l/h) under low pressure (<2.5 bar) to or very near the plants without wetting the entire soil surface. The diameter of outlets is small, the cleaning of the water is crucial for the operation of the system.

It is difficult to compare with other irrigation systems (surface and sprinkler systems) because the rotation period is longer at those systems. The system can be planned upon the water conductive and storage capacity of the soil, considering the possible amount of rainfall in order to prevent over-watering.

For microirrigation water is applied in small portions, possibly several times a day. Planning is based on daily water consumption and the other difference is that only part of the soil surface is watered. The most important practical application of microirrigation is the Queen Gil drip irrigation system, discussed below. For the drip irrigation the soil plays a primary role in the distribution of the water.

5.1. Specific attributes of drip irrigation

5.1.1. Advantages

Balanced plant development, higher productivity of better quality

With the use of the Queen Gil drip irrigation we can always provide sufficient moisture and aeration for the root zone. Therefore these factors will not limit plant development. For the irrigation rotation of the sprinkler or furrow irrigation the storage capacity of the soil is utilized; air supply is not sufficient when filled with water and the plant inputs more and more energy for water uptake as water is removed from the soil. These factors do not provide optimal background for plant development, while nutrients can be continuously utilized in the soils of constant humidity.

Accurate portioning, small water loss

The Queen Gil drip irrigation system contains lots of emitters, which allow high uniformity of output. The structure of the system secures water output with low water loss, utilization above 95% can be maintained. The economy of water utilization depends on the plant species, on the characteristics of the soil and climate and on the level of proficiency of the plant. Lower water consumption mainly results from the small area of wet surface, which reduces evaporation losses. The reduced number of water and nutrient utilising weeds is also connected to the small area of wet surface. Because of the uniform water output there is no need for over-watering some areas improving the efficiency of water utilization. The water does not have to run through the air, which would otherwise create significant (5-30%) evaporation losses.

The Queen Gil drip irrigation system is normally installed fixed near the plant so the water can be supplied any time needed, planning the irrigation rotation is easy and continuous irrigation is possible.

The irrigation is not limited by unfavourable wind conditions, the uniformity of water distribution is not affected and other manual and mechanical field works (plant protection, harvesting) also have little effect.

Uniform distribution is also possible on slopes. The Queen Gil system can be automated.

Output of nutrients, chemicals

With the Queen Gil irrigation system output of nutrients can be maintained in optimal amount and concentration according to the plant developmental stage and climatic conditions. It is possible to control nutritive value and quantity of crop yield at the same time. The output of microelements is easy and accurate.

The nutrients are released into the wet zone, where the density of the roots is the highest. This prevents leaching, which would result in nutrient loss and pollution. There are less nutrient utilising weeds present in the narrow wet zone.

Favourable plant health conditions

The leaves of the plants remain dry thus reducing the chance of fungal, bacterial and other type of infections; the chemical use just like the cost of production is reduced.

The operation of the Queen Gil drip irrigation system is favourable for the life function of the plants, the released water does not cool down, no leaf burning is induced and aeration of the soil is constantly sufficient. The unfavourable effects of large amount of rainfall following irrigation can be also prevented.

When the line spacing of the cultivated plant is wide, the distribution of weeds, which would otherwise require lots of mechanical work or the use of expensive herbicides, is reduced.

Energy saving

Installation and operation of the Queen Gil irrigation system is easy. Some types can be already operated on the pressure of 0.5 bar, which allows the pumps to be operated almost at maximum capacity. Normally the use of expensive, high-pressure proof (4 bar) materials and tools of large material need is not necessary. The use of gravity tanks is also possible.

The line spaces remain dry so harvesting, picking can be completed any time easily.

Irrigating lands of bad water regime

Continuous output can stimulate intensive production even in low water capacity sandy soils. Because of its low intensity the system can be also used on heavy clay soils.

Using brackish waters

We can use waters of higher salt content than for other types of irrigation. The reasons are: frequent output prevents the drying of the soil solution; water does not contact the plant leaves preventing leaf burning; small rate of excess water (10%) helps to leach the salts below the root zone.

5.1.2. Limitations

Clogging

When the water is contaminated by physical particles the holes of the drip irrigation system, 0.4-1 mm in size can get clogged. The contamination can be separated with different types of filters.

Precipitated salts of high dissolved salt content (e.g. calcium carbonate, iron- and manganese content) may clog the emitters, mainly at the outlets. They can also serve as feeding grounds for bacteria, the mucous organic content of which can collect physical pollutants. The hydrogen-sulphide content of water also advances the settling of bacteria inside the drainpipes.

The warm, nutrient-rich environment promotes the fast reproduction of algae and bacteria at different parts of the irrigation system, which then carried by the water flow, clog the input holes of drip irrigation elements.

Lack of high relative humidity

Some horticultural plants require high relative humidity, which is not provided by the low output evaporation. For compensation we also have to use mist blowers, humidifying sprinkler heads.

Salt accumulation near the plant

Around the edge of the wet zone near the plant (around the surface of the "onion" shaped wet zone) the salt content increases. If the drip pipe has a bad construction or the outlets are placed far from each other, the plant may fall into this zone where the conditions are not preferable for development.

5.2. Emitters

These are outlet parts of the drip irrigation system. The water running from the discharge pipe through the elements looses pressure and it is released under control through the outlets. Released on the soil surface water precipitates downwards and laterally creating a wet zone with "onion" shaped cross-section. The shape of the wet zone depends on the compaction of the soil, on soils of high clay content it is shallow and wide, while on sandy soils the shape is deep and narrow.

The outlets are available in several constructions. The small elements with a capacity of 2 l/h were developed to increase the length of the irrigation line. The bigger elements of 8 l/h capacity are used for substituting the mini-sprinkler heads.

The drip elements are classified in different ways.

a. Water flow

Most irrigation elements are planned to release a constant amount of water under a certain pressure. The catalogues normally indicate the water flow of a certain element under the pressure of 1-1.5 bar. There are some types of bodies where the water amount can be manually set for each element allowing the adjustment based on the water utilization of the different developmental stages e.g. for fruit trees without installing new elements. The setting range can be between 1-100 l/h.

The variation coefficient is used for describing and qualifying the output, this value is the best for the spiral tube drip elements (CV=0.02), the worst for porous tubes (CV=40). When the CV value exceeds 0,15, the element cannot be used for irrigation.

Changes in temperature affect the water flow of the elements. Increasing temperature lowers the inner friction of solutions, which has different effects on the water flow depending on the structure of outlets. Experimental results indicate that this change is 1.4 %/°C for microtubes, 1.2 %/°C for spiral outlets, 1-4 %/°C for nozzle types and 8% when using swirl chamber. On the other hand higher temperature increases the length of drip elements, the diameter of the holes.

b. Connection of drip elements to the tube

The in-line elements are normally placed onto the inner skirt of the tube in the factory or in the custom-built types the water flow runs inside the drip body towards the next one. On slopes water can flow down on the surface of the tube fixed to the supporting wire of the trees and runs till it is collected at a farther point (in a depression, at the supporting wire).

The on-line elements on the outer surface of the tube are installed after the tube is manufactured. Installation can be done by the manufacturer to certain distances or by the user to custom distances. For connecting the element normally a hole of 3-4 mm has to be drilled into the submain pipe of optional (normally 16 or 20 mm) diameter.

c. Pressure regulation

A flexible sheet is placed into the drip element, one side is directly connected to the water discharge pipe; the other side covers the water inlet of the drip body (see Figure 58.). If the pressure inside the pipe increases, the sheet reduces the diameter of water flow thus stabilising the amount of water to be released. Their application creates a pressure difference of 0.5-4 bar between the two ends of the discharge tube with a water-flow difference of 10-20%.

When installed the irrigation pipe can be longer. The drip irrigation line of such construction is not sensitive to pressure fluctuations and to the roughness of the surface. It increases the applicability of drip irrigation greatly on a terrain of different elevations. The duration of the controlling ability to maintain the water flow of the drip body depends on the material of the flexible sheet because most of the materials become fatigue from the continuous unilateral load.

d. Ways of pressure loss

The operation pressure of the drip irrigation systems is normally between 0.5-3 bar. The water released from the pipe can loose pressure in several ways. Contracting the output diameter reduces the amount of water output but the tendency for clogging increases. The manufacturers are trying to compensate these effects with drip bodies of different structures.

At the so-called long drive or permeable elements the water runs through a long, narrow tube. The amount of water flow depends on the length of the tube. The inner diameter of the tubes used varies between 0,6-1 mm. The roughness of the tube wall, the shape of the tube run and the structure of the maze can increase the energy loss.

For perforated water outlets the diameter of the elements is between 0.4-0.6 mm increasing the chance of becoming clogged. The energy loss can be increased by drifting water flow.

Figure 33.: Queen Gil thin-wall drip tape

Figure 33. presents the Queen Gil thin-wall drip tape. It is useful for irrigating vegetables and ornamental plants in lines, where the volume of production changes from year to year or the chemical contamination of the water is high.

The pipes containing drip elements can be of different wall thickness. This value is normally given in mil, one thousands of col. A tube size of 10 mil means a wall thickness of 250 µmm or 0.25 mm. The tubes with thicker walls have a longer lifetime, can be used under higher operating pressure, they are more expensive. The ones with the thinnest walls are planned for one irrigation season, the lifetime of the 10 mil tube is about 3 years.

The material of the tubes is polyethylene, which has a high thermal expansion resulting in elongation, deformation due to high temperature. This can be prevented if we tie the end of the tubes to a stake with a rubber band.

Measuring the uniformity of output

The drip irrigation system does not wet the entire soil surface, therefore we need a different method to evaluate the uniformity of output.

Normally the following Keller-Karmeli (1975) calculation is used. With this calculation the newly built systems can be qualified if there is no clogging or different types of installed elements, therefore the uniformity only depends on the manufacturing quality and the pressure.

$$E.U. = 100\left(1 - 1.27\frac{CV}{\sqrt{n}}\right)\frac{Q_{min}}{Q_{med}}$$

E.U. = output uniformity of the new system (in some articles mentioned as DU).

CV = manufacturer variation coefficient of the drip element (Table 14.).

Qmin = the smallest measured water amount.

Qmed = average amount of water flow.

n = the number of drip elements per plants.

Table 14.

Qualification of drip elements upon manufacture CV values

CV value	Qualification
< 0.03	excellent
0.03-0.07	good
0.07-0.10	medium
>0.10	weak

5.3. Subsurface drip irrigation

The subsurface installation of the Queen Gil drip line has several advantages over the surface installation.

- There is no evaporation losses during irrigation, the soil surface remains completely dry.
- Because of the lack of evaporation the dissolved salts do not become concentrated on the surface.
- We do not need to pick up the lines each autumn and lay them again in spring.
- The drip lines do not restrain the field works, like mechanical weed control.
- The tubes are not affected by the UV solar rays and ageing, decomposing processes of the temperature changes, therefore the lifetime may increase.
- On plantations the root zone will be deeper thus reducing the chance of falling trees, the supporting wires are not needed.
- In some types of cultures the distribution of weeds and fungal infection is also reduced.
- The branches and by-pass systems are not visible on the field, showing natural conditions.
- The buried parts are less damageable by humans or animals.

On the other hand there are some limitations of operation.

By installing the lines onto the field we create beds to be cultivated for 4-5 years. The machines have to perform cultivation at exactly the same place each year.

We have to remove the lines in every 4-5 years from the field.

The roots can enter the discharge pipes thus clogging those. Experiments indicate that the penetration can be reduced to a minimal level if irrigation is continuous and acidic fertilizers are used. When installed into deeper layers (25-70 cm) the rate of penetration is minimal.

Back suction can bring soil particles into the emitter lines inducing clogging. At the deeper parts of the area water drains from the drip lines of the irrigation section thus creating vacuum at higher parts, taking the soil particles along. We have to install air valves into the system to prevent this process.

We normally build a separate main line for rinsing the drip lines. If the rinsing main line can serve double function (irrigation-rinsing), the length of the beds can be duplicated.

The installation process requires proper equipment, which opens the ditch and lays the lines to a constant depth. The depth of installation is 10-70 cm, depending on the depth of the root zone and the texture of the soil. The distance of drip elements on the field is normally 20-30 cm, in orchard 0.25-5 m, depending on the distance of plants, recommended water flow is 2 l/h per emitter. The wall thickness of the tape should be between 8-10 mil on the field because thinner tape cannot be laid mechanically. The pressure applied can normally be higher than at surface systems, because the soil fills up with water around the outlet thus reducing water flow. After installation higher pressure is used to make the tube circular in cross-section. In plantations tubes thicker than 20 mil should be used.

According to recent experiences the subsurface drip irrigation should be used under tropical, Mediterranean climates where growing season is long and cultivation is probably continuous during the whole year.

5.4. Planning and maintaining the Queen Gil drip irrigation system

For planning a well-operating system we need to know the soil characteristics, ground water budget and the plant demands. As the first step of planning we need to find answers for three main questions.

a. The maximal *water deficiency* is the amount of water, the lack of which does not affect negatively the plant production. It is expressed in mm/ha. Calculation is based on the depth of the root zone, field water capacity and the plant water demand. The value of the root zone depth relates to the characteristic of the fully developed plant. The average value of a certain species has to be modified by local limiting factors (water blocking layer, compacted layer, high ground water level etc.).

b. The maximum allowable *application rate* depends on the characteristics of the soil, irrigation water and the vegetation. When the amount of water to be output exceeds this limit, pool formation, water runoff and erosion occurs. The average value of certain soil types has to be reduced according to the rise of the slope. Decrease the intensity by 25% till the steepness of 10% and by 50% when steepness reaches 20%.

c. The *water demand* is defined upon two values. The yearly water demand is defined by the irrigation water demand of the plants and by the water losses. From the calculated and available water content we can estimate the accuracy of production. For planning the irrigation system we should consider the peak consumption. Depending on the type of the vegetation to be watered different accuracy of water availability is required. The water availability should be 80% sure for crop species, while 90% certainty is required for vegetables and fruits. For intensive greenhouse cultivation, vegetables of high value and flower growing we should only consider the water source available during the whole irrigation period

The first step for planning the installation of the irrigation system is field survey. Measure the length of the sides; define the differences of the terrain. Draw the roads, inland water discharge lines onto the map. Mark the location and capacity of the water source. For the electric network include the available capacity and the number of possible live wires.

Define the list of the plants to be grown; planning should be based on the one with the highest water demand.

These requirements are not to be treated as strict rules but the defined limits or ranges can be useful for installation.

To construct a well-operating irrigation system we should complete the following steps:

- Calculate the maximum daily water demand of the establishment (m^3/h)
- Verify the water sources, the available water content (m^3/h), the operating pressure (bar).
- Select the type and capacity (high 8 l/h, medium 4 l/h, low 2 l/h) of the emitters.
- Define the location of the system.
- Calculate the number of sections to be built.
- Plan the diameter of the water network.
- Select the type and location of the control unit.
- Estimate the characteristics, location of the filters, safety parts and nutrient injectors.
- Select the type and location of the pump providing the required characteristics (Q, H).
- Prepare the list of material demand.
- Build up the network.

The main consideration of the system planning is to provide a uniform output of water and nutrients to meet the plant needs over the whole area. Deviation from this uniformity cannot exceed 10% over the whole system. During planning we also have to consider the type, characteristics of the drip element, the required uniformity of output, available water source, roughness of the field, soil characteristics, water demand of the plants, water quality, the method of nutrient output, the cultivation technology used and other local characteristics.

For installation the following facts should be considered.

- The input of drip lines should be on the top of the slope, rise of the slope for systems of free flow should not exceed 3% (Figure 17.). If the steepness is higher, we should use drip elements with pressure compensation or the lines have to be laid along the contours by dividing the field into several sections.
- The system has to be planned by the maximum water demand.
- For dimensioning the filtering unit we should consider the water quality, water flow and the number and method of treatments.
- At the end of the main line the valves should be easy to operate for completing the rinsing.
- It should be possible to inject the chemicals in front of or behind the filtering unit.
- It is necessary to install a water-flow meter for professional operation.
- The amount of water flow through the elements depends on the pressure applied but this is not a linear relationship. If we want to increase the diameter of the wet zone, we have to choose the elements of higher water discharge and apply higher pressure.

"Queen-Gil"®

- The distance and water output of drip elements determines how long the drip line of a certain diameter (Table 15.) can be. The length of tubes with the same diameter can be increased if we reduce the water flow through the elements.
- The other way to extend the drip line is to increase the distance of the elements from each other or use a larger diameter tube. If we apply tubes with pressure compensation, the difference in water flow between the two ends resulting from pressure differences can be eliminated with a security of ± 5 %. Thus the tube can be longer than the tubes without pressure compensating elements.
- Lay the tubes in the same direction as the beds, it is suggested to use twin-line planting and lay the tubing between the two beds. If this construction is not possible, the distance of the tubes should be as follows:

for line spacing of 45 cm, lay them in every third row;
for line spacing of 70 cm, lay them in every second row;

for plants requiring wider line spacing (cucumber, melon) lay the tubes in each row. On light, sandy soils the distance of tubes from each other should not exceed 80 cm.

Table 15.

The length of tubes with different diameters and capacities to be laid on flat ground

Tube mm	Q element L/h	EU %	Distance of the drip elements (m)							
			0.3	0.4	0.5	0.6	0.75	1.0	1.25	1.5
12 ∅	1.9	3.5	30.0	37.2	43.0	48.6	57.0	68.0	80.0	90.0
		5.0	33.1	41.6	49.0	55.2	64.5	78.0	90.0	102.0
		7.5	39.0	47.6	56.0	63.6	75.0	90.0	103.8	117.0
		10.0	43.2	52.8	62.0	70.2	82.5	99.0	116.3	130.5
	2.8	*3.5*	*22.4*	*27.7*	*32.4*	*36.7*	*43.2*	*52.2*	*60.8*	*67.5*
		5.0	*25.4*	*31.3*	*36.9*	*41.6*	*48.6*	*59.4*	*68.6*	*76.9*
		7.5	*29.2*	*36.0*	*42.3*	*48.1*	*56.0*	*68.4*	*78.8*	*86.4*
		10.0	*32.1*	*39.9*	*46.8*	*52.9*	*62.1*	*75.6*	*87.8*	*98.6*
16 ∅	2.2	3.5	44.8	55.8	66.2	88.43	88.4	108.9	127.1	143.1
		5.0	50.8	63.4	75.2	100.6	100.6	123.3	144.0	163.4
		7.5	58.9	73.8	86.9	116.8	116.8	143.1	167.6	189.0
		10.0	65.6	81.7	96.8	129.6	129.6	159.3	185.6	210.6
	4.0	*3.5*	*28.8*	*36.4*	*43.5*	*59.3*	*59.3*	*73.0*	*85.0*	*97.5*
		5.0	*32.4*	*40.8*	*48.5*	*66.8*	*66.8*	*83.0*	*97.5*	*109.5*
		7.5	*36.6*	*46.4*	*50.5*	*76.5*	*76.5*	*95.0*	*111.3*	*126.0*
		10.0	*40.2*	*51.2*	*61.5*	*84.0*	*84.0*	*104.0*	*122.5*	*139.5*
20 ∅	1.8	3.5	77.0	98.8	117.8	153.0	153.0	186.2	212.8	243.2
		5.0	90.3	115.9	138.7	195.7	195.7	238.5	271.7	310.7
		7.5	100.7	129.2	154.9	227.1	227.1	276.5	315.4	360.1
		10.0	115.9	148.2	176.7	249.9	249.9	305.0	346.8	396.2
	4.0	*3.5*	*37.4*	*49.4*	*59.9*	*84.8*	*84.8*	*105.5*	*125.2*	*145.4*
		5.0	*42.2*	*55.1*	*67.0*	*94.1*	*94.1*	*119.7*	*142.5*	*163.9*
		7.5	*47.6*	*61.6*	*75.1*	*106.9*	*106.9*	*134.9*	*161.5*	*186.7*
		10.0	*52.2*	*67.6*	*82.7*	*117.6*	*117.6*	*149.2*	*178.1*	*205.2*

Distance between the emitters

When watering plants with wide line spacing the aim is to create a continuous wet line, which means that the wet zones of the emitters should contact each other. The size of the surface area of the wet zone around one emitter depends on the ground water characteristics and the capacity of the element, as presented on Figure 16.

The distance of the drip elements should be defined as follows.

a distance of 0.1 m: on sandy soils, on perlitic nutrient peat, for the irrigation of strawberries, for several outputs a day;

a distance of 0.33 m: in greenhouses, for flower growing, for the irrigation of nurseries and shrub lines of parks;

a distance of 0.5 m: on loamy soils, in glass and plastic greenhouses and for the irrigation of the creepers in parks;

a distance of 1.0-1.50 m: in vineyards, plantations with wide spacing and in orchards.

Table 17.

The water output of the 4 l/m/hour type QUEEN GIL tube from 1 m on different pressures and slopes

Pressure (bar)	Flat surface (litre/hour)	1 % slope (litre/hour)	1 % rise (litre/hour)
0.3	3.0	3.1	1.8
0.5	4.0	4.2	3.9
0.7	5.0	5.1	4.7
1.0	6.2	6.2	5.9

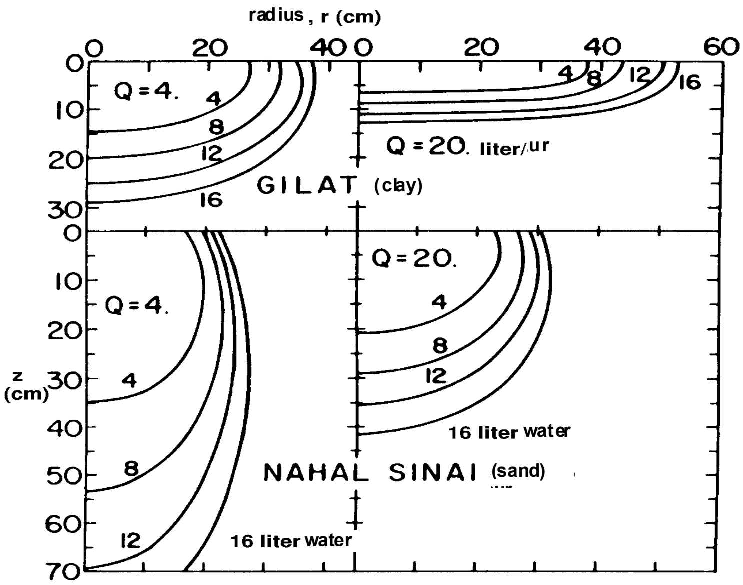


Figure 16.: penetration characteristics of soils with two different textures. On the left water flow is 4 l/h, on the right 20 l/h, the numbers along the curves indicate the actual water output. (BRESLER, 1978)

Table 17.

The recommended length of the QUEEN GIL tape to be laid under the capacity of 4 l/m/h, on different slope% and output uniformity

Slope %	Uniformity of output		
	CU=95 %	CU=90 %	CU=85 %
0	116 m	144 m	192 m
1	157 m	185 m	244 m
2	196 m	230 m	259 m

Table 18.

Manufacturing data of the QUEEN GIL tape

Characteristics	Distance of drip elements			
	10 cm	20 cm	30 cm	30 cm, full filtering
Water flow per meter per hour	2 l 4 l 8 l	4 l 6 l 8 l	4 l 6 l 8 l	4 l 6 l 8 l
Water flow per drip elements per hour	0.2 l 0.4 l 0.8 l	0.8 l 1.2 l 1.6 l	1.2 l 1.8 l 2.7 l	1.2 l 1.8 l 2.7 l
Inner diameter	12.5 mm 16.5 mm 20.5 mm	12.5 mm 16.5 mm 20.5 mm	12.5 mm 16.5 mm 20.5 mm	12.5 mm 16.5 mm 20.5 mm
Wall thickness µm (mil)	150 µm(6 mil) 200 µm(8 mil) 300 µm(12 mil) 400 µm(16 mil)	150 (6) 200 (8) 300 (12)	150 (6) 200 (8) 300 (12) 400 (16)	200 (8) 250 (10) 300 (12)
Expected lifetime	150 µm (6 mil) - 1 cultivation year 200 µm (8 mil) - 3 cultivation year 300 µm (12 mil) - 4 cultivation year 400 µm (16 mil) - 8 cultivation year			
Recommended application	General use in greenhouses for vegetable and flower cultivation. For intensive field vegetable cultures, like strawberries, cucumber, paprika, tomato, melon, horse-radish.			
	For strawberry cultures on pearlite cultivation ground			With low water filtering efficiency

The characteristic of the Queen Gil product (Figure 18.) that the distance of drip elements can be set to 10, 20, 30, 45, 90, 150 cm.

The type with the wall thickness of 16 mil is manufactured with closed emitters, can be tightened to the supporting wire in orchards, it is designed specially to support the water demand of growing trees. The user has to open the elements to the required distance. As the tree grows more and more elements become active and release the required amount.

The Queen Gil tape is packed 500, 1000 and 2000 m long rolls.

5.4.1. Main line and submain lines

Dimensioning the main line

The function of the main line is to transport the water from the pump to the distribution line. The size has to be adjusted so that the operating pressure of the emitter is provided following the pressure regulator of the last distribution line.

We have to consider the following factors to define the pressure loss for planning the main line:

a. material, length and diameter of the pipe, the amount of water to be transported,
b. the number and type of the installed fittings and shut-off valves,
c. the lane of the main line, differences of the terrain.

The main line should be laid on the shortest length possible, including the lowest number of curves, the lowest number of closing valves and other mechanisms inducing water flow loss.

Amount of water flow:

$$Q = A \times v$$

where:
Q = water flow (m^3/s),
v = the flow speed (m/s).
A = diameter (m^2),

$$A = r^2 \times \pi = \left(\frac{d}{2}\right)^2 \times \pi$$

where:
r= radius
d= diameter
π= 3.14

The speed of water flow should not exceed 3 m/s, recommended value is 1.5-2 m/s.

Instead of doing the calculations it is easier to use Figure 19., where we can read the outside diameter of the HPE tube of a given pressure range and the pressure loss according to the required water flow and flow speed.

For more irrigation sections it is recommended to place the pump onto the middle of the main line and to operate the same number of sections on the left and on the right simultaneously. This way we can reduce the length of the main drain. We can also reduce the diameter if we operate several sections simultaneously and feed the farther ones with tubes of smaller diameter. When operating the sections, the closest section to the pump on one side and the farthest one on the other side should be started at the same time.

The required water flow of a certain section of the irrigation system can be calculated by multiplying the water output of the operating pressure with the number of units.

Because of the effect of water hammer we should calculate the pressure range of the tube as 1,5 times the operating pressure. The water-flow speed should be at least 0,3 m/s to help preventing the deposition of particles. We should avoid flow speeds over 3 m/s. causing high pressure loss and strong water hammer. The pressure loss has a quadratic functional relationship with water-flow speed.

Dimensioning of the distribution line

The water transporting distribution lines carries the water to the sprinkler heads, it is connected to the main drain with a regulator head. The head can contain hydraulic- or manual valves, pressure- and flow through controls and filters.

Undersizing will result in a pressure much higher than required at the connections of the emitters. As a result the farther the emitters are from the regulator head the less water is released.

At surface plastic pipes it is possible that the rodents or woodpeckers damage the system.

Calculating the pressure drop inside the distribution lines

After each branching we have to calculate with a different value for dimensioning the distribution line because the amount of water to be transported decreases after each branch. If longer distribution line is used we can reduce the diameter of the tube gradually thus reducing costs. A specialist has to complete this type of dimensioning.

Below an easy dimensioning guide is described, which helps planning the branches of the same distance and water flow, based on constant tube diameter.

The calculation is as follows:

$J_o = J \times F_n$

where:

J_o = pressure loss of the distribution line,

J = pressure loss of the pipes of the same size without branches,

F_n= correction factor, listed in Table 19. The factor to be used depends on the distance of the first irrigation line branch from the main drain. Accordingly we have to calculate with F_{n1} when the distance of the first branch is 1/2 A and to calculate with F_{n2} when the distance of the branch is A on the irrigation line.

Planning is more difficult on slopes, where we should ask a specialist to plan the system.

Table 19.

Correction factors for calculating the pressure losses in the distribution line

number of branches	F_{n1}	F_{n2}	number of branches	F_{n1}	F_{n2}
1	1.000	1.000	16	0.363	0.382
2	0.518	0.639	17	0.362	0.380
3	0.441	0.535	18	0.361	0.379
4	0.412	0.486	19	0.361	0.377
5	0.396	0.457	20	0.360	0.376
6	0.387	0.435	21	0.360	0.375
7	0.381	0.425	22	0.359	0.374
8	0.377	0.415	23	0.359	0.373
9	0.373	0.409	24	0.359	0.372
10	0.371	0.408	25	0.358	0.371
11	0.369	0.397	30	0.357	0.368
12	0.367	0.394	35	0.356	0.365
13	0.336	0.391	40	0.355	0.364
14	0.365	0.387	50	0.354	0.361
15	0.364	0.384	100	0.352	0.356

To define the manometric delivery head demand of the pump we can use the following calculations (use the data of Table 20.):

a. delivery side

2.5 bar, the pressure required for the operation of the emitters,
0.1 bar, the emitter is located 1 m above the distribution line,
0.2 bar, because the emitter is placed on a slope higher than 2 m,
0.1 bar is the loss of the drainpipe elbow,
0.2 bar is the loss of the filter with a 20 m^3/h capacity,
0.5 bar is the loss of the pressure regulator,
0.3 bar is the increase of the filter resistance after deposition when cleaning is necessary,
0.3 bar is the pressure loss of the pipe system,
4.2 bar is the pump pressure demand.

b. suction side

0.1 bar is the pressure loss of the elements on the inlet side,
0.6 bar the operating water level is 6 m far from the height of the suction pipe.

The total manometric delivery head demand:

4.9 bar equals 49 m.

Table 20.

Informative pressure losses (bar) of pipe system accessories and fittings

The name of the element	pressure loss (bar)
centrifugal sand separator	0.1
screen filter	0.2-0.3
disc filter	0.2-0.3
gravel filter	0.10-0.25
pressure reducing valve	0.5
water-flow meter	0.8
mechanical water feeder	0.5-0.8
hydraulic valve	0.2
Dosatron nutrient injector	1.3-0.4
elbow piece	0.1
T-piece	0.1

5.4.2. Evaluation of the system

Before ordering the irrigation system the user has to evaluate the following considerations.

1. The professional experience of the builder. What is his educational background, specialities? Are there any operating reference settlements? Is he a representative of any factories?
2. The general characteristics of the system.
   What is the expected lifetime of the system elements?
   What kind of safety appliances are there?
   What are the chances for future development, extension?
   What kind of spare parts should be installed?
3. Special planning considerations.
   What will be the output uniformity of the installed system?
   Would that be possible to affect the microclimatic conditions?
   Water demand:
- How much is the daily maximum water consumption in an average year?
- How much water can be maximally released a day onto a certain area?
- How much is the estimated amount of yearly water utilization?
- What is the recommended irrigation rotation if there are several plant species cultivated on a land?

4. Energy consumption.
   Is it possible to time the water output outside the electrical peak time?
   What is the efficiency of the irrigation aggregate?
   How does the choking characteristic of the pump look like? What is the efficiency at the operating point?
   What is the cost of energy per unit area?
5. Is it necessary to filter the water? If yes, what is the method to be used?
- What is the fineness of the filters installed?
- How often do the filters require cleaning, how much water is needed and where should we place the wash-water?
- What kind of pre-filtration is required in the system?
- What is the process of washing, is it manual or automatic, do we have to take the system apart?
- Are the filters protected against external, internal surface corrosion?
- Is it possible to operate the irrigation period and the washing simultaneously?
- What kind of commissioning adjustments should be made?
- How does the change of water-flow affect the filtering of gravel filters? What kind of filter is needed to collect drifting particles? Is there a possibility to sample the cleaning water?
- How much is the maximum operating pressure of the filters?
- How much is the pressure loss of the clean filters, what is the required value to start cleaning?

6. Water treatment and nutrient solution output
- What kinds of safety appliances are required?
- How much is the capacity of the pump?
- Is the pump capable to release the nutrient solutions and chemicals?
- What kind of chemicals can be used to prevent the clogging of drip elements?
- Was there any analysis performed to define water quality?
- What elements are damaged from the chemicals?

7. Measuring the water amount.
- Is it possible to measure water flow and the amount of water simultaneously?
- How should we evaluate the hydraulic characteristics of the different sections during the installation?

8. Water flow and pressure.
- How much is the minimum pressure to be measured at the irrigation elements?
- How much is the average operating pressure and water flow of the irrigation elements?

9. Safety appliances of the system.
- Are there any air outlets and inlets installed into the system?
- What is the number, type and size of the installed valves?
- What is the pressure tolerance of the installed elements according to the overflow induced by operating pressure and water hammer?
- Is there any pressure regulator in the system?
- Do the pressure regulators require any control?

10. Warranty.
- Who is responsible for building, operating the system?
- What are the guarantee regulations of the different elements and for securing appropriate operation?
- Who is responsible to give the warranty and what are the requirements?
- Does the owner have sufficient financial background to ensure the warranty?
- How fast can we purchase the parts for repair?
- Does the builder provide mechanical descriptions of the system elements and about their operation?
- Is it possible for the builder to provide ready for operation delivery and continuous servicing?

Maintaining the irrigation system

During the operation of the drip irrigation system the biggest problem is the clogging of elements. Because there are several outlets in the system the control requires lots of labour. The level of clogging can be estimated from the decreasing diameter of the wet zone. Next to the chemical treatments rinsing the pipes can also decrease the speed of clogging. The physical pollutants passing through the filter, the present chemical and biological particles are drifting depending on the water speed. When the speed falls below 0.3 m/s, the water is not able to transport the contamination any more, which close the inlet of the elements when deposited. This problem occurs at the end of the tubes, first at the tube farthest from the input. To remove the deposits we have to open the end of the tubes and rinse the system. To define the necessary cleaning frequency, examine a tube daily about one week after starting regular irrigation if it contains deposited particles. After noticing the first pollutants we have to rinse the system according to the number of irrigation days since the start. By installing a separate mechanism for each row, automation of washing is also possible, which opens at a certain pressure (about 0.5 bar) after irrigation is done. The clogging caused by drying can be prevented when irrigated continuously of several times a day. At the end of the irrigation season clean the system with acidic solvent.

6. Operating the system

Table 21. lists the maintaining, repairing costs and the expected operating lifetime of the irrigation system elements.

Table 21.

Maintaining cost and expected operating lifetime of irrigation system elements

Name	Repairing and maintaining cost per unit of invested value (%)	Expected operating lifetime (year)
Shaft and drilled wells	0.5	25
Slush pump	4.0	15
Engines - electric - diesel - gasoline	 1.0 5.0 5.0	 25 15 9
Electric network	1.0	25
Drainpipes - steel, surface protection, subsurface - steel, surface protection, surface - aluminium, surface - PVC, HPE tubes subsurface	 0.5 1.5 2.0 0.5	 40 12 15 40
Drip lines	0.0-5.0	1-10
Valves, accessories	0.5	20

6.1. Maintenance before the irrigation season

Verify that the water supply system operates correctly.

Verify that the water-flow meters, water amount regulators operate correctly.

Calibrate the fertilizer injection after thorough cleaning.

The thorough cleaning of the filtering system is one of the most important operations to ensure safe, lasting operation of drip elements.

1. Remove the filtering cover and take out the inner element.
2. Rinse the elements with pure water-flow. For this process we can also use a soft brush.
3. Verify that the linings are undamaged then replace the elements in the filtering case. The ends of certain strainers are not identical, pay attention to this possibility during installation.

When no open water surface is present on large plantations, the surface drainpipes can be damaged by different animals. We should place troughs and keep away the animals from the field.

6.2. Operating the irrigation system

During the operation of the system we should keep the following rules.

Before starting the engine:

Check the level of fuel, lubricating oil and the water coolant.

Check the amount and composition of the fertilizer in the side tanks.

Examine the solution injectors, set the necessary feeding rate.

Verify the right position of flow control cocks.

Verify the cleanness of the filters.

During the start of the engine:

Verify that the pump operates properly.

Pay attention to strange noises, vibration.

During the operation of the engine:

Verify the appropriate pressure and water flow of the delivery side.

Check the operation of the solution injectors, the portioning.

Always check the deposition at the filters.

Set up measuring locations in the system and continuously verify that the required parameters stay constant.

Failures of pumps and possible causes

a. the pump transports little or no water at all
   Possible cause:
   - the pump and the suction pipe is not filled up totally, sealing failure,
   - there is an air chamber in the suction pipe, the foot valve did not open,
   - the suction head is too high,
   - the end of the suction pipe is not in the water or the rotation direction is not correct,
   - the loading height is larger than allowable for the pumps.
b. the pump releases water after start-up
   Possible cause:
   - the suction pipe is only filled up partially or the suction head is too high,
   - there is an air chamber in the suction pipe or air enters the system through damaged sealing,
   - the pump strainer is not deep enough in the water and air enters the machine.
c. the pump vibrates or it is too loud
   Possible cause:
   - suction head is too high and cavitation occurs, the lift of the pump is smaller or the water flow is higher than at the part of the machine with the highest efficiency,
   - the drive engine and the pump is not operated from single-shaft,
   - the bearing worn out,
   - the damaged rotating part accidentally touches the stagnant part.

The filtering system cannot remove all the particles from the water entering the tape. The remaining particles and the precipitation caused by change in temperature and pressure conditions together can form larger particles during the season. The speed of this procedure depends on the pollution (e.g. clay, dissolved organic material, salts) of the water. We might need to rinse the pipes of the low-intensity irrigation system. For this the following steps should be completed:

a. open the ends of the main line and let the water run through for at least 2 minutes,
b. close the ends of the main line and for each irrigation section open up the ends of the distribution pipes.

6.3. Winter storage of the irrigation system

Performing the appropriate maintenance ensures the long lifetime of the equipment.

a. Treat the drip lines with water of 2 pH to dissolve precipitation. Rinse the system according to the method described in point 6.2.
b. Rinse the filters, nutrient solution feeders then remove the water thoroughly.
c. The HPE tube tolerates both high and low temperatures therefore it is possible to store outdoors. However below 5 ºC, it is not allowed to roll up or down the tubes. In the storage area it is very important to keep rodents (e.g. mouse) away, we should always take precautions.
d. Pull in the piston rods of the hydraulic cylinders to prevent corrosion, cover the connections, fittings with plastic foil.
e. Unburden the tires with A frame.
f. Drain the cooling water of the internal combustion engines, drip some oil into the cylinders then spin the pistons couple times. Store the batteries away from frost and make sure to fill it up from time to time.
g. Disconnect the electric engines from the power line.

7. Appendix

7.1. Conversion tables

1 ha = 10 000 m^2	
1 cad. acre	= 5 755 m^2
1 ha = 1.74 cad. acre	
1 cad. acre	= 0.57 ha
1 mm water 1 m^2-en	= 1 litre
1 mm water 1 ha-on	= 10 m^3
1 vol% soil moisture	= 1 mm water in a 10 cm thick soil layer
1 bar	= 0.9869 atm, 75.01 cm Hg
1 atm	= 1.013 bar
1 kilopascal (kPa)	= 0.01 bar
10 meter water column	= 0.9677 atm, 0.9806 bar, 73.5 cm Hg
1 LE	= 0.7457 kW
1 ppm	= 1 mg/litre, 1 mg/kilogram, 1 g/ton
1 m/sec (24 hours)	= 86,4 km/day
1 m/sec	= 3.6 km/hour
1 l/sec	= 60 l/min, 3.6 m^3/h
1 l/minute	= 60 l/h,
1 mW/cm^2 (24 hour)	= 0.344 mm/day of water evaporation
1 mW/cm^2	= 1/70 mm/hour of water evaporation
1 decisiemens/m (dS/m)	= mmho/cm ≈ 640 mg/litre total salt content = 640 ppm

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