8 Plant Nutrients and Fertilization Management

8.1 Role of Nutrients in Crops

Apart from carbon (C), plants take up all nutrients for growth and reproduction from the soil solution. These nutrients are divided into two categories:

1. Macronutrients, divided into primary and secondary nutrients
2. Micronutrients or trace elements.

Macronutrients are needed in large quantities and have to be applied if the soil is deficient in one or more of them. In contrast with macronutrients, *micronutrients* or *trace elements* are required in only minute amounts for correct plant growth and have to be added in very small quantities when they cannot be provided by the soil. Each plant nutrient fulfills a specific role in plant growth and metabolism and one nutrient cannot be substituted by another.

8.1.1 Primary Nutrients

Within the group of *macronutrients* , which are needed for plant growth in larger amounts, the *primary nutrients* are: N, Pand K.

N is the motor of plant growth. It makes up 1 to 4 % of dry matter of the plant. It is taken up from the soil in the form of NO_3^- or NH_4^+. N is the essential constituent of proteins and amino acids.

Table 16: Comparison between NO_3^- and NH_4^+

Comparison	NH_4^+	NO_3^-
Energy consumption	It can be used directly inside the plant	It must be reduced to NH_4^+ or NH_3 before it can be used, it is energy consuming
Uptake	Uptake is favored by neutral pH values	Uptake is high and favored by low pH conditions
Effects on other nutrients	Inhibits uptake of other cations like K^+, encourages uptake of anions	Inhibits the uptake of other anions like SO_4^{2-}, encourages uptake of cations
Tolerance limits and toxicity	Excess levels produce toxic reactions	Plants can tolerate excess levels of NO_3^-
Effect on growth medium	Soil solution becomes acidic	Soil solution becomes alkaline
Susceptibility to leaching and fixation	Fixable	Very leachable

From the previous table it can be seen that plants should be nourished by a mixture of both forms to achieve balanced growth.

Nitrogen Management

When reclaimed water N, fertilizer N and plant residue N reach the soil, they become part of the soil N-cycle. The organic N in the RW is oxidized to NO_2^-, NO_3^-, and reduced to NH_4^+. Both NH_4^+ and NO_3^- remain in solution in the soil water and are taken up by crops. They are referred to as the **available N**. Most of the N in the soil stays in solution and is therefore easily leached from the root zone, eventually to groundwater resources. The following processes occur in a RW irrigated soil

- volatilization in case of high pH, NH_4^+ transforms to NH_3 and is lost to the atmosphere
- leaching in case of low system efficiency and over -application, NO_3^- is leached from the root zone by deep percolation
- denitrification in case of high organic matter contents and anaerobic soil conditions, NO_3^- is transformed to gaseous NH_3 and lost to the atmosphere
- immobilization in case of a high C/N ratio, NH_4^+ and some NO_3^- become immobile as organic N
- mineralization of organic N to plant available N
- nitrification of NH_4^+ to NO_3^-.

The effect of soil pH and pH of irrigation water on the volatilization is shown in Table 17.

Table 17: Effect of pH on volatilization of NH_3

Soil/water pH value	Potential NH_3 volatilization
7.2	1%
8.2	10%
9.2	50%
10.2	90%

Source: Burt et al. 1998

For a long term N balance the total uptake of N by plants should equal the application by fertilizers and RW irrigation, taking into account the losses by volatilization, leaching and denitrification.

The irrigation with RW might cause a supply of N on a schedule that does not match the needs of the crop. Whilst irrigating with fresh water, the farmer will fertilize with changing concentrations during the growing season. During the later ripening or maturing stages of the crop it is customary to cease N fertilization completely. With RW the farmer has no control over the N concentration in it. Therefore, the season is divided into three periods.

1. **The beginning of the irrigation season:** Small doses of water are distributed, so the quantities of N are lower than the required amount for growth (time of deficit). In this period it is possible that there is a need for additional fertilization. This should be done according to the recommendations of the extension service.
2. **Mid-irrigation season**: Large quantities of water are applied, so the quantities of N are usually equal to the N demands of crops.
3. **End of irrigation season**: The irrigation with RW means a continuation of the application of N during this period, where it is usual to stop the N fertilization (time of excess). There can be negative effects on crops as a result of this excess, such as
   - high vegetative growth and low reproductive growth
   - delay of ripening of fruits and the harvested parts of the crop.

Phosphorus Management

P makes up 0.1 to 0.4 percent of the dry matter of the plant and plays a key role in the transfer of energy and photosynthesis. It is essential for the development of the tissues which form the growing points of the plant.

P in soils occurs both in organic and inorganic forms of phosphate ($H_xP_yO_z$), stable and unstable. From the adsorbed buffer at the soil particles, the concentration of soluble P is kept more or less constant when soluble P-levels decrease due to plant uptake. Most of the P applied to the soil stays in the top soil, especially under low-rate drip or sprinkler irrigation, where the soluble P has more time to be adsorbed or precipitated before being leached to the subsoil.

For a long term P balance, the total uptake of P by plants should equal the application by fertilizers and RW, especially since there is little loss by leaching.

Excessive levels of P lead to deficiencies in the micro-nutrients Cu, Zn and Fe (Ryden and Pratt, 1980). However, this problem will only occur in case of excessive RW application rates. The environmental problem associated with breakthrough of P is eutrophication of surface waters. This is unlike the case in the monitored region, since P-levels in the RW used in the JV are low to moderate.

No specific actions are necessary for P management in case of RW irrigation. Only in case of low-rate sprinkler or low-rate drip irrigation there might be a problem of too little P availability as a result of adsorption in only the topsoil due to too little downward water movement. In general the P supply by RW is sufficient to meet crop needs. Timing of P application is not an issue due to the storage and releasing capacity of most soils.

Potassium Management

K makes up 1 to 4 percent of the dry matter of the plant and has many functions. It plays a vital part in carbohydrate and protein synthesis. It is taken up from the soil in the form of the K^+ - cation

The interaction of K^+ applied by RW is similar to the interaction of phosphates, except for the fact that release of K^+ to the soil solution is much slower than in case of phosphates. Therefore a more continuous supply of K^+ over the growing season should be ensured. K^+ is available in the soil in the form of exchangeable and non-exchangeable soil-particle bound K^+, and K^+ in the soil solution. The percentage of soil particle bound K^+ is higher in case of clay soils with high Cation Exchange Capacity (CEC). High levels of Ca^{2+} and Na^+ enhance the release of K^+ from the soil particles, so in case of RW applied K^+, most of it will be available for uptake in the soil solution. However, leaching of K^+ below the root zone remains a slow process.

For long term K balance the total uptake of K by plants should equal the application by fertilizers and RW, especially since there is little loss by leaching.

K content in RW is highly variable and dependent on the treatment method used, and most of the time is higher than the N content (the exception here is Kufrinija). Ranges observed for secondary treated RW are 10 - 40 mg/l, and in order to achieve maximum crop yield, K application should be monitored over the growing season to determine necessary additional fertilization. K deficit can be monitored well by plant tissue analysis and by analysis of the K availability in the soil.

Excess application of K is not reported in literature to have any negative side effects. Deficit application of K^+ will decrease plant turgor, plant water uptake and transpiration thus reducing plant growth.

In order to supply the crop with sufficient K in case of irrigation with RW, additional K should be given by fertilization, above all during vegetative development.

8.1.2 Secondary Nutrients

The *secondary nutrients* are *Ca, Mg* and *sulphur*. Plants also take them up in considerable amounts.

Calcium is essential for root growth and as a constituent of cell wall materials. Though most soils contain sufficient Ca, deficiency may occur on strongly Ca-depleted soils.

Magnesium is the main constituent of chlorophyll, the green pigment of the leaves that functions as the engine of photosynthesis. Some 15 to 20 percent of the Mg contained in the plant is found in the green parts.

Sulphur (S) is an essential constituent of protein and also involved in the formation of chlorophyll. In most plants it makes up 0.2 to 0.3 (0.05 to 0.5) percent of dry matter.

Calcium, Magnesium and Sulphur Management

Ca^{2+} and Mg^{2+} are often present in large quantities in RW. In addition to their positive effect on water quality related to soil physicochemical conditions, they are important nutrients. The level of Ca^{2+} and Mg^{2+} in calcareous soils is usually satisfactory and Ca and Mg fertilization is usually not required. Sulphur is also important for plant growth, since S is one of the essential nutrients. The presence of SO_4^{2-} in RW can be therefore advantageous in S deficient soils (Feigin et al., 1991).

The equation to calculate Ca, Mg and S applications with fertilizer is similar to the equations for P and K applications. Since Ca^{2+} and Mg^{2+} are retained by the soil, a high fertilizer efficiency of 90% applies. In case of SO_4^{2-}, leaching occurs more rapidly and lower fertilizer efficiency, depending on the DU, of around 75%, should be taken into account.

8.1.3 Micronutrients

The *micronutrients* or *trace elements* are iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), chlorine (Cl) and boron (B). They are among the key substances in plant growth. Being taken up in minute amounts, their range of optimal supply is very small. Their plant availability depends primarily on the soil reaction. Over-supply of some trace elements such as boron might lead to toxicity and have an adverse effect. In most cases this happens when the pH is low to very low.

Table 18: List of plant nutrient concentrations, forms of absorption and roles in plant

Nutrient	Typical concentration in plant	Forms of absorption by plant	Role in the plant
N	1 - 5%	NH_4^+, NO_3^- and urea	Protein syntheses
P	0.1 - 0.4%	$H_2PO_4^-$, HPO_4^{2-}	Energy storage and transfer (ATP)
K	1 - 4%	K_+	All physiological and biochemical processes
Ca	0.2 - 1%	Ca^{2+}	Structure and permeability of cell membrane, cell elongation and division
Mg	0.1 - 0.4%	Mg^{2+}	Primary constituent of chlorophyll
S	0.1 - 0.4%	SO_4^{2-}	Necessary for synthesis of S-containing amino acids (90% of S in plants is in amino acids)
Cl	0.2 - 2%	Cl^-	Osmotic and cation neutralization
Fe	50 - 250 ppm	Fe^{2+}, Fe^{3+}, and chelated Fe	Structural component of porphyry molecules which are involved in oxidation-reduction reactions
Mn	20 - 500 ppm	Mn^{2+}	Photosynthesis and oxidation-reduction process
Zn	25 - 150 ppm	Zn^{2+} and organic complexes	Enzymes activities, production of growth hormones (auxins)
B	20 - 60 ppm	H_3BO_3 is the major form	New cell development, proper pollination, translocation of sugars and P, nodule formation in legumes, amino acids synthesis
Cu	5 - 20	Cu^{2+} and organic complexes	Involved in enzymes and cannot be replaced by any other metal ion
Mo	>1 ppm	MoO_4^{2-}	Essential in nitrate reductase enzyme

Source: adapted from Samuel et al. 1993

8.2 Nutrient Uptake from the Soil

In the soil, clay minerals and organic matter retain nutrients in a plant available form at the *soil adsorption complex* . The ability of a soil to retain a certain amount of nutrients (*soil adsorption capacity*) determines the natural fertility of a soil. Nutrients carry positive charges (+) (cations) or negative charges (-) (anions). According to these charges they are attracted by the clay minerals and organic matter.

The soil water containing the nutrients in dissolved plant-available form is called the *soil solution* . The plant root can take up nutrients only in dissolved form. Therefore, they have to be released from the adsorption complex into the soil solution to be effectively plant-available. In the soil there exists equilibrium (balance) between the nutrients adsorbed on the soil particles and the nutrients released into the soil solution. The strength of attraction by the adsorption complex differs with different nutrients. In case of cations it is primarily influenced by the charge they carry. Aluminum (Al^{3+}) is most strongly held by the adsorption complex, followed by metallic microelements (such as iron, manganese and zinc) and K^+, NH_4^+, Ca^{2+} and Mg^{2+}. With the anions, PO_4^{3-} is highly immobile and strongly held by certain positively charged portions of clay minerals and soil constituents like Ca, iron and aluminum. On the contrary, chlorine (Cl^-) and NO_3^- tend to stay in the soil solution, remain mobile and move along with the soil water to the roots (mass flow) when the plants take up water, or they are washed out. Sulphate (SO_4^{2-}), like NO_3^- remains relatively mobile and is also liable to leaching.

Plants take up nutrients selectively as a function of the cation-anion balance in the crop and the pH of the soil. The concept of the *cation-anion balance* means that the total number of nutrient cations (positively charged) in a plant must equal the total number of nutrient anions (negatively charged ions) in a plant. If this is not the case, the plant will become electrically charged. Therefore, the uptake of one nutrient might inhibit the uptake of another nutrient. Documented interactions are displayed in Table 19 (Burt et al. 1998).

Table 19: Nutrient interactions as a function of cation-anion balance

Uptake of this nutrient	Decreases uptake of these nutrients	Increases uptake of these nutrients
NH_4	Mg, Ca, K, Mo	Mn, P, S, Cl
NO_3	Fe, Zn	Ca, Mg, K, Mo
P	Cu, Zn	Mo
K	Ca, Mg	Mn (on acid soils)
Ca		Mn (on acid soils)
Mg	Ca, K, S	Mo
Fe	Cu, Zn	
Zn	Cu	
Cu	Zn, Mo	
Mn	Zn, Ca, Mo	

Source: Burt et al.1998

Because of this principle of selective uptake, the main plant nutrient, N, should always be applied in both forms of NH_4^+ and NO_3^-, or in the form of urea (no charge).

Similar inhibited nutrient uptake patterns occur as a result of pH changes in the soil. In the process of transforming nutrients and nutrient uptake in the plant, H^+, HCO_3^- and OH^- ions are formed and released to the soil, modifying the soil pH value. As the soil pH value is a major factor in the solubility of nutrients, this process might inhibit or enhance the uptake of certain ions, as illustrated in Table 20 (after Singer and Munns, 1996).

Table 20: Nutrient uptake problems as a function of soil pH

Soil pH value	Related problem
< 5	Al and Mn toxicity, P, Ca and Mo deficiency.
< 5.5	Mo, Zn, K and S (sulphur) deficiency, decreasing P availability
> 7.5	Zn and Fe deficiency, decreasing P availability
> 8.4	P, Zn and Fe deficiency.

Source: after Singer and Munns 1996

8.3 Fertilization Management

The majority of the farmers in the JV have drip irrigation systems and accordingly they practice fertigation. This means that commercial fertilizers are applied with irrigation water. Fertigation has many advantages when compared with conventional fertilizer application, most of all the relatively precise placement of the nutrients in the root zone and the flexible scheduling. To set up a proper fertigation program, farmers or extension workers should know

- the actual crop demand
- available dissolved nutrients in irrigation water
- levels of nutrients in soil and manure
- requirements for different growth stages.

Farmers should apply only the difference between what the cultivated crop is demanding and what is available in soil, irrigation water and manure.

$R_{fert} = R_{crop} - (R_{soil} + R_{irrig} + R_{manure})$ where R = Requirement

In addition to the calculated crop requirements some supplements/allowances need to be added to compensate for losses and/or (temporary) unavailability of nutrients/fertilizers. Such 'correction factors' are explained in the following chapters.

Due to the fact that the RW used for irrigation in the JV contains nutrients (see chapter 2.1.1) the following chapters will provide details and practical examples and calculations for their use.

8.3.1 Target Yield and Crop Requirements

Before determining the nutrient and fertilizer requirements the farmer should decide if he is aiming for high, medium or low yield levels. Under-estimating the yield goal might result in yield loss due to under-fertilization. Alternatively, over-estimating the yield goal might result in over-fertilization. A first orientation regarding the requirements of crops is the amounts that are removed or taken up from soils by particular crops depending on the yields. In general – as Table 21 depicts – the literature provides a relatively wide range of removal or uptake values, depending on yields, soil types, climatic zones and other factors.

Searching for the most suitable figures can be time consuming and even confusing. A comprehensive approach is given in IFA (1992): Based on averages over some 40 different vegetable crops that were widely grown in temperate regions, the uptake per metric ton (t) of yield may be estimated to be around 5.1 kg of N, 0.96 kg of P and 2.3 kg of K. For some crops slight specifications are given. These ranges can be taken as first orientation when assessing nutrient requirements. Multiplying these removal values per ton with the envisaged yield provides the nutrient requirement, although it has to be noted that such linear simplification does not exactly reflect the complex processes in plant nutrition. Crop removal for N is relatively inefficient and results in average N losses of 50% because of leaching, volatilization, denitrification and immobilization. Consequently crop removal values reflect a minimum amount of N required (Zublena, 1997). Most resources of crop nutrient removal take into account only the nutrients removed with the harvest portion of the plant and do not account for the above-ground biomass and roots. For this reason and to be on the safe side RWP recommends the IFA figures because they are relatively high. In order to come to more precise and adjusted recommendations RWP highly recommends more national research on crops nutrients removal under JV conditions and for different vegetable cultivars.

Tomato harvest

Table 21: Amounts of N, P and K removed per each ton of produce (kg/t).

Crop	Source	N	P	K
Cucumber	International Fertilizer Industry Association **(IFA)**	**2 - 4**	**0.4 - 0.8**	**3**
	United States Department of Agriculture (**USDA**)	1.1	0.23	1.9
	National Center for Agricultural Research & Technology Transfer (**NCARTT**)	1.80	0.60	2.50
Tomato	**IFA**	**2 - 4**	**0.4 - 0.8**	**3.5**
	USDA	1.50	0.3	2.6
	NCARTT	2.80	0.60	3.10
	California Fertilizer Association (CFA)	2.70	0.30	4.20
	Food & Fertilizer Technology Center (FFTC)	2.75	0.25	3.25
Pepper	**IFA**	**2 - 4**	**0.4 - 0.8**	**3.5**
	USDA	1.6	0.3	1.6
	NCARTT	2.10	0.50	3.50
	FFTC	3.25	0.90	5.50
Potato	**IFA**	**5**	**0.35**	**5.5**
	USDA	3.7	0.6	4.6
	CFA	5.40	0.90	9.30
Squash	**IFA**	**2 - 4**	**0.4 - 0.8**	**3**
	USDA	1.9	0.3	2.2
	CFA	3.80	0.40	4.50
Eggplant	**IFA**	**4 - 5**	**0.4 - 0.8**	**3.3 - 3.5**
	USDA	1.8	0.22	2.1
	NCARTT	2.90	0.30	4.20
	FFTC	3.25	0.25	2.75
Onion	**IFA**	**2 - 4**	**0.4 - 0.8**	**3**
	USDA	2.10	0.40	1.20
Okra	**IFA**	**2 - 4**	**0.4 - 0.8**	**3**
	USDA	3.2	0.63	2.8
Date palm	USDA	3.2	0.4	6.50

After assessing the targeted yield per dunum (du) the crop demand is calculated according to

$$\text{Crop requirement (kg/du)} = \text{expected yield (t/du)} \times \text{nutrient requirement (kg/t)} \qquad \textbf{Equation 15}$$

Example: A tomato grower using KTR irrigation water cultivates tomato on clay loam and irrigates on an average 400 m^3 (400 mm) per season per du and expects 16 t of tomato yield. He applies two tons of poultry manure.

Calculating Crop Nutrient Requirement

According to Table 21 and equation 15, average removal of tomato, and requirement for 16 t yield per dunum is as follows:

$$\text{N requirement (kg/du)} = 16\ (\text{t}) \times 3\ (\text{kg/t}) = 48\ \text{kg}$$

$$\text{P requirement (kg/du)} = 16\ (\text{t}) \times 0.6\ (\text{kg/t}) = 9.6\ \text{kg}$$

$$\text{K requirement (kg/du)} = 16\ (\text{t}) \times 3.5\ (\text{kg/t}) = 56\ \text{kg}$$

Nutrients in RW

Reclaimed irrigation water in the central and south JV contains dissolved nutrients, which can be used by plants. Therefore it is necessary to consider dissolved nutrients coming with irrigation water when setting up a fertigation program. Table 22 shows the average values of three major nutrients (mg/l) for the years 2003-2005 for two major sources, KTR and KAC-south. For comparison the nutrient content of KAC-north is also shown.

It is important to mention that the JVA will display the water quality data for KTR and KAC-south water from summer 2006 onward monthly at the stage offices and pump stations in the JV. This will give farmers the opportunity to adjust their fertigation schedules at a time based on previous month's total nutrient applications.

Table 22: Average values (mg/l) for N, P and K in different water sources in the central and southern JV

Water sourc	NO_3-N + NH_4-N	PO_4-P	K
KTR	18.6	3.9	26.1
KAC-south	18.4	3.1	26
KAC-north	1.4	0.23	10.5

Source: JVA and RSS labs, 2003-2005.

From Table 22, a farmer can calculate the amount of nutrients received with irrigation water as follows:

Calculating Nutrients in Irrigation Water

$$\text{Amount of N (kg)} = \frac{\text{Amount of irrigation water } (m^3) \times \text{Amount of N in the irrigation water (mg/l)}}{1{,}000}$$

$$\text{Amount of N (kg)} = \frac{400 \times 18.6}{1{,}000} = 7.4 \text{ kg}$$

$$\text{Amount of P (kg)} = \frac{\text{Amount of irrigation water } (m^3) \times \text{Amount of P in the irrigation water (mg/l)}}{1{,}000}$$

$$\text{Amount of P (kg)} = \frac{400 \times 3.9}{1{,}000} = 1.6 \text{ kg}$$

$$\text{Amount of K (kg)} = \frac{\text{Amount of irrigation water} (m^3) \times \text{Amount of K in the irrigation water (mg/l)}}{1{,}000}$$

$$\text{Amount of K (kg)} = \frac{400 \times 26.1}{1{,}000} = 10.4 \text{ kg}$$

It is clear from this example that irrigation water provides 7.4 kg of N, 1.6 kg of P and 10.4 kg of K. Accordingly the tomato farmer who uses KTR water for irrigation needs

Requirements (kg/du) – nutrients in irrigation water (kg) = new requirement (kg/du)

N: 48 kg – 7.4 kg = 40.6 kg

P: 9.6 kg – 1.6 kg = 8 kg

K: 56 kg – 10.4 kg = 45.6 kg

Nutrients in Manure

Manure is well known for its beneficial impacts on soils due to its content of organic matter. In addition manure contains nutrients depending on the producing animal, the fodder and storage. Table 23 depicts the content of the primary nutrients N, P and K in percentage per ton of three different types of manure.

Table 23: Nutrients contents (%) of different types of manure.

Manure	N	P	K
Poultry and sheep	0.9%	0.22%	0.66%
Cow	0.5%	0.13%	0.41%

Source: Ecochem

Accordingly two tons of poultry manure is equivalent to N = 18 kg, P = 4.4 kg and K = 13.2 kg.

It is important to mention two major points here

- Rate of mineralization

  Manure contains nutrients in organic forms that are unavailable for plants as they need time to be mineralized. The general rule of thumb for N mineralization rate of organic N is 30% in the first year. An exception is poultry manure where almost 70% of organic N becomes available in the first year. The availability of P and K in manure is similar to that in commercial fertilizers. For all manure types 90% of P and K are considered available in the first year.

- Timing of incorporation

  Considerable amounts of N will be lost if manure is not applied and incorporated immediately into the soil. Between 30 - 70% of N is lost depending on how long farmers leave manure on the field before incorporation. After two days about 50% of N will be lost. Most farmers in the JV do not incorporate manure immediately; therefore not more than around 30% of N is available for plants. Losses in P and K are far less and account for 5 - 15 % (Samuel et. al., 1993) (see Table 24).

Table 24: Availability of nutrients and (%) nutrients loss

Manure type	(%) available N in the first year	(%) N loss	(%) available P, K in the first year	(%) P and K losses
Poultry	70	(30 -) 70	90	15
Sheep	30	(30 -) 70	90	15
Cattle	30	(30 -) 70	90	15

Source: Ecochem and Samuel et al., 1993.

Chicken manure

If two tons of poultry manure is applied, the amounts of N, P and K can be calculated as follows:

Calculating Nutrients in Manure

$$\text{Amount of N (kg)} = \frac{\text{Amount of manure (kg)} \times \text{\% N available in first year} \times (1 - \text{\% N loss}) \times \text{\% N in manure}}{100}$$

$$= \frac{2{,}000\ \text{kg} \times 0.7\ \text{\% N available in first year} \times (1 - 0.7\ \text{\% N loss}) \times 0.9\ \text{\% N in manure}}{100} = 3.8\ \text{kg}$$

$$\text{Amount of P (kg)} = \frac{\text{Amount of manure (kg)} \times \text{\% P available in first year} \times (1 - \text{\% P loss}) \times \text{\% P in manure}}{100}$$

$$= \frac{2{,}000 \times 0.9 \times (1 - 0.15) \times 0.22}{100} = 3.4\ \text{kg}$$

$$\text{Amount of K (kg)} = \frac{\text{Amount of manure (kg)} \times \text{\% K available in first year} \times (1 - \text{\%K loss}) \times \text{\% K in manure}}{100}$$

$$= \frac{2{,}000 \times 0.9 \times (1 - 0.15) \times 0.66}{100} = 10\ \text{kg}$$

These amounts should be deducted from the total nutrients requirement as with the nutrients in irrigation water. Accordingly, the total requirements of the example after deduction of nutrients in irrigation water and manure are

requirements (kg/du) – nutrients in irrigation water (kg/du) – nutrients in manure (kg/du) = new requirement (kg/du).

N = 48 kg – 7.4 kg – 3.8 kg = 36.8 kg

P = 9.6 kg – 1.6 kg – 3.4 kg = 4.6 kg

K = 56 kg – 10.4 kg – 10 kg = 35.6 kg

for one dunum.

Nutrients in Soil

Regular soil testing is an important element in nutrient management; it can be used as a diagnostic tool or to identify trends over time. To obtain meaningful test results, the samples must be taken correctly at the same time each year.

JVA Lab

Parameters to be analysed

The RWP has excellent relations with the JVA lab in the JV and highly recommends that farmers take composite soil samples for each plot cultivated with different crops and bring them to the lab at Dahret al Ramel. Table 25 lists the recommended parameters that should be analysed, the frequencies and cost. Soil texture and cation exchange capacity do not change in the long run but they are basic information -especially the texture - for assessments of irrigation and fertilizer management, as can be also concluded from the various tables in these guidelines. The knowledge of these soil properties is worth their financial cost. The salinity and nutrient contents should be checked yearly at the beginning of the season to know the fertility status of the soil. The cost per field will be 26.5 JD for a complete set of analyses and 16.5 JD for EC and main nutrients.

Table 25: Recommended soil test parameters

Parameter	Frequency	Cost (JD)
Soil texture	once	5
Cation exchange capacity (CEC)	once	5
Electrical Conductivity (EC) and pH	yearly, beginning of season	1.5
Total Nitrogen (T-N)	yearly, beginning of season	4
Phosphorous (P)	yearly, beginning of season	3
K	yearly, beginning of season	3
Ca	yearly, beginning of season	1.5
Mg	yearly, beginning of season	1.5
Soil preparation	yearly	2

Cost of analysis source: JVA director lab, 2006

Nitrogen

Plants absorb N as NO_3^- and/or NH_4^+. Soil tests can determine NO_3^- at the time of sampling but do not reflect future processes in the soil. Therefore, total N analysis for estimating the soil N supplying capability is recommended. Only around 4% of total N will become plant available during one growing season (Marx et al. 1999). The lab gives the result in %. Net N-mineralization rates of 0.05 to 0.2 kg N/du/day are common (Magdoff, 1991). N in the soil is subject to many losses, among them leaching, volatilization and denitrification. Therefore, estimating the N amounts that would be available for the plant during a growing season should take into account all these losses. Accordingly soil test results for N should be multiplied by a correction factor ranging from 0.4 - 0.65 (average about 0.55) depending on the soil type. N in sandy soils is multiplied by 0.4, which means it is assumed that only 40% of N will be available for plant and the rest might be lost due immobilization, volatilization, and denitrification and leaching.

Phosphorus

P soil tests results are an index of P availability. Test values can be used to calculate available P if biological and chemical factors are considered. One of the chemical factors is the lime content of the soil, which interacts with P and reduces its availability significantly depending on lime content (given in %). The soils of the JV are high in lime content (> 25%); therefore one should expect high reduction in the availability of P. Since it is impossible to assess the influence of all factors it is highly recommended not to consider the entire P (in ppm or mg/kg) given by the lab. P is an immobile element in the soil, mostly limited to the upper layer of the soil (not more than 15 cm depth). P values should be multiplied by a correction factor ranging from 0.35 - 0.6 (average about 0.48) depending on soil types to consider adsorption and re-sorption of P and as well as changing P forms from the readily available forms to non-available forms, the latter as a result of reaction with Ca and Mg.

Potassium

The lab gives the result as total available K in ppm or mg/kg, which includes both exchangeable and soil solution K. Although exchangeable K is readily available to plants, its release from exchangeable sites to soil solution is governed by many factors. When plants absorb K from soil solution, the soil reacts to the shortage in soil solution by releasing some exchangeable K to the soil solution. This process takes place only if another cation replaces K on the exchange complex. The rate of K release from exchangeable sites to soil solution differs from one soil to another. Therefore it is recommended not to consider all available K but a fraction of it depending on the soil type. As a rule of thumb, a correction factor should be applied to the given value from the lab test. K should be multiplied by a correction factor ranging from 0.45 - 0.65 (average about 0.57) depending on soil types to consider the rate of K release from clay and organic matter to the soil solution.

Factors Affecting Availability of Nutrients in the Soil and Soil Test Interpretation

With regard to the interpretation of soil analyses results the following factors should be taken into consideration:

Soil Factors

- *Soil texture*, which is an indication of clay, sand and silt content and the resulting cation exchange capacity (CEC). Theoretically soils with high clay content have high CEC, which means that a lot of K is attracted to exchangeable sites on clay minerals; therefore high CEC soils have higher ability to compensate any soil K shortage in soil solution. This process is limited by the availability of other cations to replace K on the exchangeable sites. Soils differ in their rate of K release to soil solution
- *pH,* which influences the availability of nutrients to plants especially P and micronutrients
- *Ca and lime content*: High content of lime decreases P availability
- *Organic matter content*: High organic matter content improves micronutrient availability
- *Soil temperature*: high temperatures increase N mineralization rate and P availability.

Plant Factors

- Plants can be classified into three major categories according to their nutrient requirements: *Light feeders, moderate feeders and heavy feeders* (Woods End, 1997), therefore plant requirements differ greatly according to the category in which the plant belongs. These differences are due to the expected harvested portions in addition to genetic differences between plants.

Cropping Factors

- *Root depth*: shallow rooted plants, like most vegetables, are limited to the amounts of nutrients available in the upper layer of the soil (20 - 30 cm), whereas deep-rooted plants can make use of nutrients in deeper depths up to 80 cm.

- *Wetting percent*: in drip irrigation systems only part of the field is wetted; therefore plant nutrients uptake is limited to the wet part of the soil. As a rule of thumb 35 - 60% of the soil is wet under drip irrigation depending on spacing between plant rows. Nevertheless, the wetting percentage might be 100% depending on soil types, infiltration rate and lateral movement of water.

RWP is aware of the fact that, for a grower, the goal is to maintain plant nutrients at a level for sustained productivity and profitability, which means that nutrients should not be a limiting factor at any stage from plant emergence to maturity. Stemming from this fact, and for the sake of simplicity, proposed sufficiency levels (see also chapter 9.1) of analysed parameters are suggested in these guidelines for different crops and for different soil types. It is very important to mention that these critical levels were developed based on crop nutrients requirements and expected efficiency of different nutrients in different soil types, as well as common agricultural practices under drip irrigation systems and good crop management.

Table 26 shows analysis results for a clay loam, sampling depth was 0.3 m, wetting percentage was 60%.

Table 26: Soil test results for N, P and K

Soil texture	Clay loam
Total N	0.10%
P	50 ppm
K	150 ppm

To convert these values from ppm and % to kg/du, the soil bulk densities of Table 27 can be used.

Table 27: Soil texture and bulk densities

Soil texture	Bulk Density(kg/m^3)
Sand	1,600
Loamy sand	1,550
Sandy loam	1,500
Loam	1,400
Silt loam	1,350
Sandy clay loam	1,350
Clay loam	1,350
Silt clay loam	1,350
Sandy clay	1,300
Silt clay	1,250
Clay	1,200
Average	1,380

Source: USDA

Calculating Nutrients in Soil:

N content for 30 cm depth of the soil:

$$N(\text{kg/du}) = \frac{N(\%) \times \text{soil bulk density } (\text{kg/m}^3) \times \text{area } (\text{m}^2) \times \text{soil depth}(\text{m}) \times \text{N mineraliztion factor } (\%) \times \text{N correction factor} \times \text{wetting } (\%)}{100}$$

Equation 16

$$= \frac{0.1 \times 1{,}350 \times 1000 \times 0.30 \times 0.04 \times 0.55 \times 0.6}{100} = 5.3\text{kg/du}$$

To have a rough estimate of total N for most soil types and assuming an average of 50% wetting area and average bulk density 1,380 kg/m^3 and a depth of 30 cm the previous equation can be simplified to

$$N(\text{kg/du}) = \%\ \text{Total N} \times 45.5$$

Equation 17

P for the first 15 cm of the soil

$$P(\text{kg/du}) = \frac{P(\text{ppm}) \times \text{soil bulk density} \times \text{soil depth} \times \text{P correction factor} \times \text{wetting } \%}{1{,}000}$$

Equation 18

$$= \frac{50 \times 1{,}350 \times 0.15 \times 0.48 \times 0.6}{1{,}000} = 2.91\ \text{kg/du}$$

To have a rough estimate of P for most soil types and assuming an average of 50% wetting area and average bulk density 1,380 kg/m^3 and a depth of 15 cm the previous equation can be simplified to

$$P(\text{kg/du}) = P(\text{ppm}) \times 0.049$$

Equation 19

K for 30 cm depth of the soil

$$K(\text{kg/du}) = \frac{K(\text{ppm}) \times \text{soil bulk density} \times \text{soil depth} \times \text{K correction factor} \times \text{wetting } \%}{1{,}000}$$

Equation 20

$$= \frac{150 \times 1{,}350 \times 0.3 \times 0.57 \times 0.6}{1{,}000} = 20.8\ \text{kg/du}$$

To have a rough estimate of K for most soil types and assuming an average of 50% wetting area and average bulk density 1,380 kg/m^3 and a depth of 30 cm the previous equation can be simplified to

$$K\,(kg/du) = K\,(ppm) \times 0.12 \qquad \textbf{Equation 21}$$

Back to the example of the tomato grow, clay loam will be able to provide plants with about
N = 5.3 kg/du, P = 2.9 kg/du and K = 20.8 kg/du

Farmers should deduct these quantities from the total crop requirements. Accordingly the tomato crop of the example requires

Requirements (kg/du) – nutrients in irrigation water (kg/du) – nutrients in manure (kg/du) – nutrients in soil (kg/du) = new requirement (kg/du)

N = 48 kg – 7.4 kg – 3.8 kg – 5.3 kg = 31.5 kg

P = 9.6 kg – 1.6 kg – 3.4 kg – 2.9 kg = 1.7 kg

K = 56 kg – 10.4 kg – 10 kg – 20.8 kg = 14.8 kg

for one dunum.

When comparing these quantities with the calculated crop nutrients requirements (48 kg N, 9.6 kg P, and 56 kg K, respectively), it is clear that farmers can save about 35 - 75 % fertilisation cost, depending on the nutrient.

Finally the calculated amounts of nutrients should be increased to compensate for the inefficiency of irrigation system and irregular distribution of water and nutrients. Therefore, the calculated amounts of nutrients should be divided over 0.75 to account for DU. Accordingly the tomato farmer should apply on one dunum:

N = 31.5 kg / 0.75 = 42 kg/du

P = 1.7 kg / 0.75 = 2.3 kg/du

K = 14.8 kg / 0.75 = 19.7 kg/du

If soil samples are taken after adding manure to the soil, result of soil analysis will represent both soil nutrients and nutrient added by manure.

8.3.2 Determining Amounts of Fertilizers to be Applied

So far, the net quantities of the three primary nutrient requirements have been calculated. These are still rather abstract figures; for a practical and busy farmer it is more important to know the amount of his preferred fertilizer that supplies these nutrient requirements to the crops.

The following steps explain the procedure.

Step 1: Choose the fertilizers you want to buy. Table 28 shows the main fertilizers used in the JV and their grades or composition.

Table 28: Common and available fertilizers used in the JV

Fertilizer	Grade (N-P_2O_5-K_2O)	Available primary nutrients
Urea	44-0-0	N
Ammonium sulphate	21-0-0	N
Ammonium nitrate	33-0-0	N
Urea phosphate	17-44-0	N, P
Diammonium phosphate (DAP)	18-46-0	N, P
Monoammonium phosphate	11-48-0	N, P
K nitrate	13-0-44	N, K
K sulfate	0-0-50	K

Note that P and K are given in the traditional way as P_2O_5 and K_2O. To convert use

$$P_2O_5 \times 0.44 \rightarrow P; \qquad P \times 2.29 \rightarrow P_2O_5$$

$$K_2O \times 0.83 \rightarrow K; \qquad K \times 1.2 \rightarrow K_2O_5$$

Based on long experience and the general conditions in the JV the RWP recommends

- ammonium sulphate as N source
- urea phosphate as a phosphorous source
- K nitrate as a K source.

These recommendations do of course not exclude the use of other fertilizers; they are based on the following advantages.

Ammonium sulphate

- lowers the pH of the soil, due to its acidity
- N in the form of NH_4^+
- increases the availability of micro-nutrients by decreasing the pH.

Urea phosphate

- lowers the pH of the soil (CON_2H_4 + urease + soil = CO_2 and NH_3. $NH_3 + H^+ = NH_4^+$)
- P content is high (44 %)
- N in the form of urea.

K nitrate

- K content is high (44 %)
- contains N in the form of NO_3^-; plants need a mixture of NO_3^- and NH_4^+ forms.

Step 2: Calculate the amounts of chosen fertilizer as follows

$$\text{Amount of nitrogen fertilizer} = \frac{\text{Amount of N nutrient} \times 100}{\text{\% of N in the fertilizer}} \qquad \textbf{Equation 22}$$

$$\text{Amount of phosphorus fertilizer} = \frac{\text{Amount of P nutrient} \times 100}{\text{\% of P in the fertilizer} \times 0.44} \qquad \textbf{Equation 23}$$

$$\text{Amount of potassium fertilizer} = \frac{\text{Amount of K nutrient} \times 100}{\text{\% of K in the fertilizer} \times 0.8} \qquad \textbf{Equation 24}$$

Since phosphate fertilizers (in this example urea phosphate) and K fertilizers (in this example K nitrate) also contain N, the required amounts of both fertilizers are calculated first, and then the N amount in both is calculated.

$$\text{Amount of N in P fertilzer} = \text{Amount of P fertilizer} \times \text{\% of N in P fertilizer}$$

$$\text{Amount of N in K fertilzer} = \text{Amount of K fertilizer} \times \text{\% of N in K fertilizer}$$

Step 3: Add the amounts of N in P and K fertilizers and deduct them from the net amount of required N

Step 4: Calculate the amount of N fertilizers as in Equation 22.

Step 5: Multiply the quantities of calculated fertilizers by the area to be fertigated.

Example:

Returning to the tomato example, the required amounts of nutrients for one dunum are N = 42 kg, P = 2.3 kg and K = 19.7 kg. The farmer wants to use ammonium sulfate, urea phosphate and K nitrate.

Calculation for one dunum

Since P and K fertilizers also contain N, the amounts of urea phosphate and K nitrate should be calculated first.

$$\text{Amountof urea phosphate} = \frac{2.3 \times 100}{44 \times 0.44} = 11.9 \text{ kg/du}$$

$$\text{Amount of potassium nitrate} = \frac{19.7 \times 100}{44 \times 0\ 83} = 54 \text{ kg/du}$$

$$\text{Amount of N in urea phosphate} = 11.9 \times 0.17 = 2.0 \text{ kg}$$

$$\text{Amountof N in potassium nitrate} = 54 \times 0.13 = 7 \text{ kg}$$

$$\text{Amount of N required} = 42 \quad (2+7) = 33 \text{ kg}$$

$$\text{Amount of ammonium sulfate} = \frac{33.3 \times 100}{21} = 157 \text{ kg}$$

8.3.3 Nutrients Distribution for Different Crop Stages

Plants require nutrients for all stages but at different quantities. The required amounts of macronutrients increase with time; the peak demand for N is during the vegetative growth stage, for P from starting of flowering, whereas peak demand for K is during vegetative and flowering stages. Table 29 shows weekly N fertigation for the different stages for vegetable crops under Californian conditions. It is obvious that N fertigation varies according to crop stages.

Table 29: Weekly N fertigation estimate of (gross) requirements of vegetable crops under California conditions

Crop	Growth stage	Approximate N fertilizer requirements (kg N/du/week)
Cucumber	Vegetative growth	0.56 - 1.11
	Early flowering and fruit setting	1.11 - 2.22
	Fruit bulking	1.11 - 1.67
	First harvest	0.56 - 1.11
Pepper	Vegetative growth	0.56 - 1.11
	Early flowering and fruit setting	1.67 - 3.33
	Fruit bulking	1.67 - 2.22
	First harvest	0.56 - 1.11
Squash	Vegetative growth	0.56 - 1.11
	Early flowering	1.11 - 2.22
	First harvest	0.56 - 1.11
Tomato	Vegetative growth	0.56 - 1.11
	Early flowering and fruit setting	1.11 - 2.22
	Fruit bulking	1.11 - 1.67
	First harvest	0.56 - 1.11

Source: Hartz, 1994

Example:

In the previously given example, the calculated amounts of fertilizers are: 158.5 kg ammonium sulfate, 11.9 kg urea phosphate and 51.6 kg K nitrate. How should these quantities be applied during different crop stages to one dunum?

It is recommended to divide the stages of the crop into four and then estimate the expected length of each stage. Percentages of nutrients uptake for the major nutrients are given in Table 30. This table is valid for most vegetables and for the three major nutrients according to project's observation and many other resources. However, certain vegetables can be exceptional like potato, where N and phosphorous should not be given in the last stage. In general the farmer should depend on his experience regarding the expected life of the crop and the length of the stages because both life and lengths of the crops differ according to the date of planting and the weather conditions.

Table 30: Percentages of total nutrient uptake during different growth stages

Stage	% of nutrients' uptake	Length of the stage
Vegetative	15	45
Early flowering - beginning of fruit set	25	60
Fruit ripening and harvesting	55	90
Final stage (senescence)	5	20

Depending on the previous table, the farmer can distribute these fertilizers according to the following formula

$$\text{Amount of a fertilizer / week} = \frac{\text{Required amount of fertilizer(kg)} \times \text{\% of nutrient up take for the stage} \times 7}{\text{length of the stage (day)}}$$

Equation 25

Table 31: Weekly amounts (kg) of different fertilizers required for fertilizing one dunum of tomato

Fertilizer	Vegetative stage	Flowering and fruiting	Ripening and harvesting	Senescence
Ammonium sulphate	3.7	4.6	6.7	2.7
Urea phosphate	0.3	0.3	0.5	0.2
K nitrate	1.3	1.6	2.3	1

From the previous tables and project's observations one can conclude the following

- all crops stages require the three primary nutrients but at different levels or percentages
- it is essential to provide plants with sufficient quantities of K at the first two stages.

Apart from that it is also worth mentioning that

- P is an immobile nutrient and tends to react with other nutrients in the irrigation water and become less available; therefore farmers could also apply about 50% of total P requirement before planting
- with regard to K and P there is no problem of leaching as it is the case with NO_3^-; therefore, farmers could apply most of the crop needs of K and P in the first two stages of plant growth.

9 Environmental Aspects

Apart from agronomic aspects, farmers should pay attention to environmental aspects. One of these aspects is the "Sufficiency Level Concept" which is introduced in Chapter 9.1. This concept would not only give way to an ecological ease, but also to an economic gain, as farmers would obtain higher gross margins. The implementation and spreading of such concepts and the results achieved on the demonstration plots (Appendix) show the farmers that it is possible to reduce input amounts without having yield losses.

9.1 Sufficiency Level Concept

This concept is based on developing critical levels of nutrients above which adding fertilizers may not contribute to higher yield. The nutrient sufficiency approach to soil testing, when adequately calibrated, promises the best method of achieving highest economic yield while conserving resources and preserving environmental integrity (Olson et al., 1981).

Soil Sampling

Many laboratories classify the fertility level of soil as very low, low, medium, high or very high based on the quantity of nutrients extracted. In general the grower easily understands very low to very high. However, crops differ in their requirements; and what is low for potato may be high for wheat and what is low for a clay loam may be high for a sandy loam. Sufficiency levels under drip irrigation and fertigation will be several times greater than sufficiency levels for traditional fertilizers and irrigation regimes because (i) "traditional" practices often have a larger wetted root zone and (ii) "traditional" practices often have banded zones of some fertilizers, such as phosphorous, around which the availability is much higher than for the root zone as a whole (Burt et al, 1998).

The sufficiency approach is the best approach, both economically and environmentally to be used in interpreting soil test results; however, many factors should be considered before applying this method. This approach depends on developing critical levels for each nutrient in different soil types and for different crops.

Table 32: Proposed critical levels for P and K in different soil types and for different crop categories

Crop Category	Soil texture	P (ppm)	K (ppm)
Light feeder crops (less than 2 t/du) beans, peas, squash	coarse textured soils	15	52
	medium textured soils	19	66
	fine textured soils	23	50
Medium feeder crops (less than 5 t/du) potato, pepper	coarse textured soils	37	131
	medium textured soils	46	165
	fine textured soils	57	122
Heavy feeder crops (less than 10 t/du) tomato, cucumber, eggplant	coarse textured soils	73	261
	medium textured soils	93	331
	fine textured soils	114	249
Very heavy feeder crops (Plastic houses) (more than 10 t/du) tomato, cucumber	coarse textured soils	125	444
	medium textured soils	158	562
	fine textured soils	193	424

* These values are only guidelines under drip irrigation conditions
Source: adjusted from Woods End research laboratory, 1997

Table 32 gives interpretation guidelines to soil test results. Table 33 shows two tests results that can be interpreted accordingly.

Table 33: Soil test results for N, P and K in two different soil types and for two different crops

Parameter	Sample 1	Sample 2
Crop	Potato	Squash
P (ppm)	50	35
K (ppm)	150	130
Soil texture	Sandy loam	Silt clay

Sample 1: Sandy loam is a coarse textured soil and potato is considered a medium feeder crop because it produces less than 5 t/du. From Table 32 it is clear that P in sample 1 (50 ppm) is higher than the critical level (37 ppm) and K in sample 1 (150 ppm) is higher than K critical level (131 ppm). Therefore, it is not recommended to add either P or K.

Sample 2: Silt clay is a fine textured soil, and squash is light feeder crop. P in this soil (35 ppm) is higher than the P critical level (23 ppm); K in soil sample (130 ppm) is also higher than K critical level in soil (50 ppm). Accordingly, the probability of yield increase as a result of adding P and K in this case is very low; therefore, it is not recommended to add these nutrients.

This example clarifies the effect of crop and soil texture in soil test interpretation. Although the amounts of P and K in sample 2 are less than P and K in sample 1, it is not recommended to add P and K fertilizers in sample 2.

10 References and Useful Literature

Allen, R.G., Pereira, L. S., Raes, D. and Smith, M. (1998): Crop evapotranspiration Guidelines for computing Crop Water Requirements. FAO Irrig. Drain. Pap. 56, FAO, Rome.

Asano, T. (1998): Water Quality Management Library. Volume 10/Wastewater Reclamation and Reuse. CRC Press LLC.

Banco, F. F. and Folegatti, M. (2003): Evaporation and crop coefficient of cucumber in greenhouse. Revista Brasileira de Engenharia Agricola e Ambiental V.7, n.2, p 285-291.

Battikhi, A. M. and Hill, R. W. (1986): Irrigation scheduling and watermelon yield model for the Jordan Valley. J. Agronomy and Crop Science 157: 145-155.

Baumhogger, W. (1949): Ascariasis in Darmstadt and Hessen as seen by a wastewater engineer. Zeitschrift fur Hygiene und Infektionskrankheiten 129: 488-506. (in German).

Burman, R. D., Cuenca, R. H., and Weiss, A. (1983): Techniques for estimating irrigation water requirements. Adv. Irrig. 2: 335-394.

Burt, C., O'Conner, K. and Ruehr, T. (1998): Fertigation. Irrigation Training and Research Center, Cal Poly, San Luis Obispo, pp 295.

Burt, C. and Styles, S.W. (1999): Drip and Micro Irrigation for Trees, Vines, and Row Crops. ITRC, pp 292.

California Fertilizer Association (1995): Western Fertilizer Handbook, 8th Edition. Interstate Publishers, Danville, Ill.

California Plant Health Association (2002): Western Fertilizer Handbook 9th Edition, Prentice Hall, US.

Ecochem, Manure - Animal Faeces or Value Added Commodity.

FAO,(1984): Localized Irrigation.Irrigation Drainage Paper no :36.

FAO, (1996): Irrigation methods and water management by A.P. Savva. TCP/LEB/4554.

Faust, J. E. (2002): Light management in greenhouses. http//www.firstinfloriculture.org/pdf/2002–5.

Feigin A.,Ravina I.,and J. Shalhevet 1991. Irrigation with treaed sewage effluent:Management for environmental protection. Springer-Verlag, Berlin: 224 pp.

Freney, J. R., Peoples, M.B., and Mosier, A.R. (1995): Efficient Use of fertilizer Nitrogen by Crops. Food and Fertilizers Technology Centre.

Fernandandez, M. D., Gallardo, M., Bonachela, S., Orgaz, F. and Fereres, E. (2000): Crop coefficients of a pepper grown in plastic greenhouses in Almeria, Spain. ISHS, Acta Horticulturae 537:

Garrison, S. (2002): Best Management Practices for Irrigating Vegetables. Rutgers Cooperative Extension. The State University of New Jersey.

GTZ (2003): Guidelines for Brackish Water Irrigation in the Jordan Valley, Brackish Water Project, Amman, Jordan.

GTZ (2004a): Practical Recommendations for Nutrient Management under Irrigation with Reclaimed Water. RWP, Amman, Jordan.

GTZ (2004b): Evaluation of Irrigation and Fertilizer Practices for Main Crops on Monitored Farm Units and Irrigation with Reclaimed Water in the Jordan Valley. RWP, Amman, Jordan.

GTZ . (2006): Analysis of Irrigation and Fertigation Practices using Reclaimed Water in the Jordan Valley. RWP, Amman, Jordan.

GTZ and JVA (2006): Irrigation Water Quality Guidelines. RWP and JVA, Amman, Jordan.

GTZ (2006): Economic Aspects of the Use of Reclaimed Water in Irrigated Agriculture in the Jordan Valley. MoWI, JVA, RWP and AHT Group. Amman and Essen.

Guy, F. (2001): Using PET for Determining Crop Water Requirements and Irrigation Scheduling, Irrigation Technology Centre, Texas University.

Hageman, R. H. (1984): Ammonium vs. Nitrate Nutrition of Higher Plants. Roland D. Hauck (Ed.). Nitrogen in Crop Production. American Society of Agronomy, Inc., Madison, WI. Pp 67-85.

Hallmark, W.B., Adams, J.F., Morris, H.F and Fontenot J.D. (1986): Effect of Plant Growth Stage on Detection of Soybean Nutrient Deficiencies. Journal of Fertilizer Issues.3 (3):66-71.

Hansen, H. and Trimmer, W. (1997): Irrigation Runoff Control Strategies. Publication of Oregon State University, PNW 287.

Hartz, T. K. (1994): Drip Irrigation and Fertigation Management of Vegetable Crops. California Department of Food and Agriculture. Sacramento, A.

Hartz, T. K. (2000): Drip Irrigation and Fertigation Management of Celery. Celery Grower Guidelines, Vegetable Research and Information Centre.

Hartz, T. K. and Hochmuth, G. J. (2001): Fertility Management of Drip-irrigated Vegetables. UC Davis, Vegetable Research and Information Centre.

Hegde, D. M. (1997): Nutrient Requirement of Solanaceous Vegetable Crops. Food and Fertilizer Technology Centre. Maharashtra, India. www.agnet.org/library/article/eb441.html

Hochmuth, G. J. (2001): Fertilizer Management for Greenhouse Vegetables Production Handbook-Volume 3

http://npk.nrcs.usda.gov

International Fertilizer Association (1992): World Fertilizer Manual. IFA, Paris

Kansas State University, Soil Test Interpretations and Fertilizers Recommendations. MF 2586

Kaspersma, J. M. (2001): Treated wastewater use in irrigation: Calibration of the model SWAP for determination of leaching and salt accumulation under drip irrigation with treated wastewater in Jordan. M. Sc.-Thesis, Wageningen.

Krey W. (1949): The Darmstadt Ascariasis epidemic and its control. Zeitschrift für Hygiene und Infektionskrankheiten 129: 507-518 (in German).

Magdoff, F. (1991): Understanding the Magdoff pre-side dressing nitrate test for corn. J. Proc. Agric. 4:297-305.

Marx, E. S. and Stevens, R.G. (1999): Soil Test Interpretation Guide. Publication of Oregon State University Extension Service, EC 1478.

Mazahrih, N.T. (2001): Evapotranspiration measurement and modelling for Bermuda grass, alfalfa, cucumber, and tomato grown under protected cultivation in the Central Jordan Valley. Ph. D.-Thesis, University of Jordan.

Mazahrih, N.T., Hamdan, H., Kresa, M., Alawneh, Y., and Ayesh, M. (2004): Determination of Actual Evapotranspiration and Crop Coefficient for Hot Pepper (Capsicum annum L.) Inside Plastic Houses. Paper presented during Water Demand Management Conference 2004, Dead Sea, Jordan.

Jordan Climatologically Handbook (2003): Meteorological Department.

Mikkelsen, R.L. (1989): Phosphorus Fertilization through Drip Irrigation. Journal of Production Agriculture. 2:279-286.

Olson, R. A., Frank, K. D., Grabouski, P. H. and Rehm, G. W. (1981): Economic and Agronomic Impacts of Varied Philosophies of Soil testing. Agronomy Journal 74:492-499.

Qwasmi, W. (2001): Assessing Fertilization Requirements for Cucumber Crop under Plastic Houses Conditions. NCARTT, Bulletin no.165/2001.

Rawls, W. J., Brakensiek, D. L., and Saxton, K. E. (1982): Estimation of Soil Water Properties. Transactions, American Society of Agricultural Engineers, 25(5):1316-1320, 1328.

Rosen, C and Eliason, R. (1995): Nutrient Management for Commercial Fruit & Vegetable Crops in Minnesota. Produced by Communication and Educational Technology Services, University of Minnesota Extension Service.

Ryden, J. C., and Pratt, P. F. (1980): Phosphorous removal from wastewater applied to land. Hilgardia 48 (1):1-36

Safadi, A. S. (1991): Squash and cucumber yield and water use models. Unpublished Ph.D. Dissertation, Dept. Biological and Irrigation Engineering, Utah State Univ., Logan, UT 84322-4105.

Samuel, L., Nelson, W.L., Beaton, J.D. and Havlin, J.L. (1993): Soil Fertility and Fertilizers. Fifth Edition. Canada, pp 643.

Sanchez-Levya, R. (1976): Use of wastewater for irrigation in District 03 and 88 and its impacts on human health. M.Sc. thesis. School of Public Health, Mexico City. (in Spanish).

Sarraf,S.(1999): Irrigation management and maintenance in greenhouse crops in Lebanon. FAO, Beirut

Sehgal, R. and Mahajan, R. C. (1991). Occupational risks in sewage work. Lancet-British-edition. 338; 8779: 1404-1405.

Shuval, H. I., Yekutiel, P. and Fattal, B. (1984): Epidemiological evidence for helminth and cholera

Shuval, H. I., Adin, A., Fattal, B., Rawitz, E., and Yekutiel, P. (1986): Wastewater irrigation in developing countries. Health effects and technical solutions. World Bank Technical Paper 51, 324pp.

Singer, M. J. and Munns, D. N. (1996): Soils - an introduction. 3rd edition, Prentice-Hall, Inc.

Tanji, K. K. (1990): Agricultural Salinity Assessment and Management. Editor: American Society of Civil Engineers, New York, N.Y.

The Potash Development Association: Potash manuring for arable crops.

Thomas, W. L., Stevens, R. G., Topielec, R. R. and Neibling, W. H. Soil Water Monitoring and Measurement. Pacific Northwest publication, PN0475.

Tremblay, N., Scharpf, H., Weier, U., Hélène, L. and Josée O. (2001): Nitrogen Management in Field Vegetables - A guide to efficient fertilization. Publication of HRDC.

USAID (2005): Fertilization program for the demonstration sites in the Jordan Valley. Kafa'a Project.

Woods End Research Laboratory, (1997): A basic Guide for Interpreting Soil Test Values, ME 04352.

Zublena, J.P. (1997): Soil Facts: Nutrient Removal by Crops in North Carolina. North Carolina Cooperative Extension Service.

11 Annexes

11.1 List of Reviewers and Participants of Technical Workshop

Name	Organization
Dr. Abdel Nabi Fardous	DG NCARTT
Fayez Bataineh	JVA
Tayseer Ghezawi	JVA
Dr. Ahmad Abu Awwad	UoJ
Dr. Muhammad Al Duqqah	UoJ
Dr. Ahmad Bulad	NCARTT
Dr. Mohammad Al Mazraawi	BAU
Dr. Mohammed Jitan	NCARTT
Dr. Ziad Al-Ghezawi	JUST
Dr. Mahmoud Safi	NCARTT
Nayef Seder	JVA
Yousef Hasan	JVA
Guillaume Panzani	MREA
Qais Owais	JVA
Mahmoud Al Akhras	Private company
Zuhair Madadha	JVA
Muhammad El Amar	JVA
Dr. Naomi Sabillon	KAFA'A
Dr. German Sabillon	KAFA'A
Mohammad Shaban	KAFA'A
Ihab Hammoudeh	JOHUD
Fuad Salameh	Farmer
Sameer Fazzaa	Farmer
Abadalla Yousif Awad	Farmer
Dr. Boening-Zilkens	Consultant
Artur Vallentin	GTZ
Sameer Abdel-Jabbar	GTZ

11.2 Results of Demonstration Sites

Table 34: Results of demonstration plot 1

Demo Summary 1

Crop		Tomato		**Location**	Abu Obaidah
Date of planting		05/10/2005		**Water source**	KTR
Variety		Newton		**Plot size (du)**	0.824
Farmer		Mazraawi		**DA**	22
Nutrient	N	P	K	**FU**	141
Crop demand (t/kg)	3.20	0.60	3.5	**Irrigation efficiency**	75.00
Expected production(t/du)		21.4		**Crop water requirement (mm/du)**	480
Total crop demand (kg)	68.37	12.82	74.77		
Water contribution (kg)	4.88	1.36	9.13	**Soil type**	clay loam
Soil contribution (kg)	40.82	5.25	80.15	**Expected crop life (days)**	215
Net total crop demand (kg)	22.67	6.21	-14.51		

Comparison

	N (kg/du)	P (kg/du)	K (kg/du)	Cost(JD/du)	Irrigation (m^3/du)	Harvest (t/du)	Harvest (box/PH)
Demo	27.8	8.1	8.4	39.5	480	15.3	664
Control	42.9	5.9	50.0	86.7	576	13.7	592
Ratio	1.5	0.7	6.0	2.2	1.2	0.9	0.89

Difference in production (t/du)	Value of production difference (JD/du)	Value of difference in fertilization and production (JD/du)	Total value of difference in fert.+prod.+irrig. (JD/du)
1.6	292.4	339.5	340.2

% of water and soil contributions in providing plants with their nutrients requirements

% of contribution	N	P	K
Water	7	11	12
Soil	60	41	107

Table 35: Results of demonstration plot 2

Demo Summary 2					
Crop	Cucumber			**Location**	Deir Alla
Date of planting	14/09/2005			**Water source**	KTR
Variety	Fadia			**Plot size (du)**	1.41
Farmer	Hasan Abu Sido			**DA**	21
Nutrient	N	P	K	**FU**	23
Crop demand/ton (kg)	3.00	0.60	3	**Irrigation Efficiency**	75 %
Expected production(t/du)		18.8		**Crop water requirement (mm/du)**	249.1
Total Crop Demand (kg)	56.26	11.25	56.26		
Water contribution (kg)	4.27	1.19	8.00	**Soil Type**	clay
Soil Contribution (kg)	5.49	2.51	154.13	**Expected crop life (days)**	135
Net Total Crop Demand(kg)	46.49	7.55	-105.88		

Comparison							
	N (kg/du)	**P (kg/du)**	**K (kg/du)**	**Cost(JD/du)**	**Irrigation (m^3/du)**	**Harvest (t/du)**	**Harvest (box/PH)**
Demo	60.1	8.7	5.5	69.6	249.1	10.8	723
Control	54.0	16.4	65.1	140.7	263.1	10.7	716
Ratio	0.9	1.9	11.9	2.0	1.1	1.0	0.99

Difference in production (ton/du)	Value of production difference (JD/du)	Value of difference in fertilization and production (JD/du)	Total value of difference in fert.+prod.+irrig. (JD/du)
0.1	22.4	93.5	93.8

% of water and soil contributions in providing plants with their nutrients requirements			
% of contribution	**N**	**P**	**K**
Water	8	11	14
Soil	10	22	274

Table 36: Results of demonstration plot 3

Demo Summary 3

Crop	Tomato			**Location**	Abu Obaidah
Date of planting	25/09/2005			**Water source**	KTR
Variety	-			**Plot size (du)**	1.56
Farmer	Hasan Abu Sido			**DA**	22
Nutrient	N	P	K	**FU**	141
Crop demand/ton (kg)	3.20	0.60	3.5	**Irrigation Efficiency**	75 %
Expected production(ton/du)		19.7		**Crop Water Requirement (mm/du)**	461
Total Crop Demand (kg)	63.14	11.84	69.06		
Water contribution (kg)	3.86	1.08	7.23	**Soil Type**	clay
Soil Contribution (kg)	8.34	2.34	160.24	**Expected crop life (days)**	205
Net Total Crop Demand(kg)	50.93	8.42	-98.41		

Comparison

	N (kg/du)	P (kg/du)	K (kg/du)	Cost(JD/du)	Irrigation (m^3/du)	Harvest (t/du)	Harvest (box/PH)
Demo	65.2	9.7	6.6	76.5	461	16.3	1060.7
Control	60.2	15.5	54.9	151.0	530	16.3	1060.7
Ratio	0.9	1.6	8.3	2.0	1.1	1.0	1.0

Difference in production (ton/du)	Value of production difference (JD/du)	Value of difference in fertilization and production (JD/du)	Total value of difference in fert.+prod.+irrig. (JD/du)
0	0	74.4	75.2

% of water and soil contributions in providing plants with their nutrients requirements

% of contribution	N	P	K
Water	6	9	10
Soil	13	20	232

Table 37: Results of demonstration plot 4

Demo Summary 4

Crop		Cucumber		**Location**	Abu Obaidah
Date of planting		18/10/2005		**Water source**	KTR
Variety		Melin		**Plot size (du)**	0.9
Farmer		FAZZA		**DA**	24
Nutrient	N	P	K	**FU**	33
Crop demand/ton (kg)	3.00	0.60	3	**Irrigation Efficiency**	75 %
Expected production(ton/du)		19.7		**Crop Water Requirement (mm/du)**	495.0
Total Crop Demand (kg)	59.10	11.82	59.10		
Water contribution (kg)	4.46	1.25	8.36	**Soil Type**	silty clay loam
Soil Contribution (kg)	10.06	5.13	81.05	**Expected crop life (days)**	205
Net Total Crop Demand(kg)	44.57	5.45	-30.31		

Comparison

	N (kg/du)	N (kg/du)	N (kg/du)	Cost(JD/du)	Irrigation (m^3/du)	Harvest (t/du)	Harvest (box/PH)
Demo	56.6	6.3	5.6	62.8	495	15.3	810
Control	57.4	13.4	40.4	155.5	510	14.8	784
Ratio	1.0	2.1	7.2	2.5	1.03	0.96	0.96

Difference in production (ton/du)	Value of production difference (JD/du)	Value of difference in fertilization and production (JD/du)	Total value of difference in fert.+prod.+irrig. (JD/du)
0.5	64.7	157.5	157.6

% of water and soil contributions in providing plants with their nutrients requirements

% of contribution	N	P	K
Water	8	11	14
Soil	17	43	137

Table 38: Results of demonstration plot 5

Demo Summary 5					
Crop		Cucumber		**Location**	Abu Obaidah
Date of planting		15/11/2005		**Water source**	KA C
Variety		189		**Plot size (du)**	0.882
Farmer		Abdullah		**DA**	21
Nutrient	N	P	K	**FU**	23
Crop demand/ton (kg)	3.00	0.60	3	**Irrigation Efficiency**	75 %
Expected production(ton/du)		20.0		**Crop Water Requirement (mm/du)**	431
Total Crop Demand (kg)	59.85	11.97	59.85		
Water contribution (kg)	0.34	0.08	3.44	**Soil Type**	silty loam
Soil Contribution (kg)	5.96	4.68	79.70	**Expected crop life (days)**	180
Net Total Crop Demand(kg)	53.55	7.22	-23.29		

Comparison

	N (kg/du)	N (kg/du)	N (kg/du)	Cost(JD/du)	Irrigation (m^3/du)	Harvest (t/du)	Harvest (box/PH)
Demo	67.6	7.6	5.7	74.5	431	16.4	802
Control	38.4	9.7	16.0	113.8	481	16.4	803
Ratio	0.6	1.3	2.8	1.5	1.1	1.0	1.00

Difference in production (ton/du)	Value of production difference (JD/du)	Value of difference in fertilization and production (JD/du)	Total value of difference in fert.+prod.+irrig. (JD/du)
0.0	- 1.2	38.1	39.0

% of water and soil contributions in providing plants with their nutrients requirements

% of contribution	N	P	K
Water	1	1	6
Soil	10	39	133

11.3 Duration of Pre-Irrigation (Example)

An important variable to be considered when practicing pre-irrigation is the application rate of the irrigation system. The examples shown in Table 39 help to clarify this point.

Table 39: Different cases of water application rates and acreage

Case	A	B
Soil type	loam	loam
ECe (dS/m)	10	10
Area (m^2)	500	1000
Emitter Discharge (l/h)	3.5	6.5
Emitter spacing (m)	0.3	0.4
Rows spacing (m)	1	2

In both cases the EC_e and soil types are alike and the only difference is the application rate of the irrigation system.

From Table 9 the required amount of water for pre-irrigating a loam soil with EC_e = 10 dS/m is 111 mm.

Application rate (case A) = 3.5 l/h / (0.3 m * 1 m) = 11.6 mm/h

Application rate (case B) = 6.5 l/h / (0.4 m* 2 m) = 8.1 mm/h

Operation time (case A) = 111 mm / 11.6 mm/h = 9.6 h = 9 h 36 min

Operation time (case B) = 111 mm / 8.1 mm/h = 13.7 h = 13 h 42 min

It is important to mention here that for effective pre-irrigation in terms of salts leaching it is recommended to apply water once or twice at a maximum and without waiting for a few days between each application. The majority of farmers in JV practice pre-irrigation and they apply water in portions and then wait for a few days and apply the next quantity. This practice is not recommended for the following reasons

- significant amounts of water will evaporate from the soil surface when farmers wait for a few days
- effective pre-irrigation requires that water applied to the soil saturates the first 30 cm of the soil, because only water above FC will move down into deeper depths.

11.4 Guidelines for Irrigation Water Quality

Table 40: Guidelines for irrigation water quality proposed by RWP

Parameter	Unit	Threshold
pH		6-9
EC	dS/m	Sensitive plants: < 1.7 Medium tolerant plants: 1.7 - 3.0 Tolerant plants: 3.0 - 7.5 Highly tolerant plants: >7.5
Temperature	°C	4°C - 30°C
Total Suspended Solids (TSS)	mg/l	< 50
Biological Oxygen Demand (BOD_5)	mg/l	< 60
Chemical Oxygen Demand (COD)	mg/l	< 120
Calcium (Ca)	mg/l	< 400
Mg	mg/l	< 150
Sodium Absorption Ratio (SAR)	mg/l	6 - 9
K	mg/l	< 80
Bicarbonate (HCO_3^-)	mg/l	< 520
T-N	mg/l	< 50
NH_4-N	mg/l	< 16
Sulfate (SO_4)	mg/l	< 960
Boron (B)	mg/l	< 6
Iron (Fe)	mg/l	< 1
Manganese (Mn)	mg/l	< 2.0
Zinc (Zn)	mg/l	< 2.0
Copper (Cu)	mg/l	< 1.0
Escherichia coli	Most probable number/100 ml	1000
Intestinal Helminthes eggs	Egg/l	< 1

For more information see “Irrigation Water Quality Guidelines”, GTZ, 2006.

11.5 Example Calculation for Tomato on Open Field

General input data

Parameter:	Source/ Data input	Unit:	Source:	Remarks:	
Crop:	Tomato		Farmer		
Cultivation:	Open field		Farmer		
Acreage:	8	du	Farmer		
Meteorological station:	Karamah		Farmer		
Distance between rows:	1.6	m	Farmer		
Emitter spacing:	0.4	m	Farmer		Farm data
Emitter flow rate:	4	l/h	Farmer		
Transplanting Date:	26.9.2003		Farmer		
Last Harvest:	18.3.2004		Farmer		
Vegetation duration	175	days	calculated		
Vegetation duration	25	weeks	calculated		
Yield	6.7	t/du	Farmer		
Irrigation source:	KAC south		Farmer		
N	18.4	mg/l	Table 22		Water source data
P	3.1	mg/l	Table 22		
K	26	mg/l	Table 22		
$EC_{\text{Irrigation water}}$	2		Table 2		
Soil type:	Loam		Soil analysis	0-0.3m	
N	0.16	%	Soil analysis	0-0.3m	
P	96.5	ppm	Soil analysis	0-0.15m	Soil data
K	502	ppm	Soil analysis	0-0.3m	
EC_{soil}	4.06	dS/m	Soil analysis	00.3-m	
Manure application:	1250	kg/du	Farmer		Manure data
Manure type:	chicken		Farmer		
Fertilizer application:					
Ammonium sulfate:			Table 28		
N	21	%	Table 28		
Diammonphosphate			Table 28		Fertilizer data
N	18	%	Table 28		
P_2O_5	46	%	Table 28		
Potassium nitrate			Table 28		
N	13	%	Table 28		
K_2O	44	%	Table 28		

Calculating guideline data

Parameter:		Unit:	Source:	Remarks:
CWR coverage approach:	328	mm	calculated	
FWR coverage approach:	383	mm	calculated	
CWR Kc approach:	322	mm	calculated	
FWR Kc approach:	377	mm	calculated	
Net depth:	13	mm	Table 10	
Gross depth: 0-15 cm	19	mm	calculated	always higher than highest weekly irrigation amounts in first 8 weeks
Gross depth: 0-30 cm	37	mm	calculated	always higher than highest weekly irrigation amounts
Gross depth: 0-50 cm	62	mm	calculated	always higher than highest weekly irrigation amounts
Gross depth: 0-70 cm	87	mm	calculated	always higher than highest weekly irrigation amounts
Infiltration rate:	11	mm/h	Table 11	
Application rate:	6	mm/h	calculated	
Pre-irrigation requirement	96	mm	Table 9	Loam 0.3 m
Crop nutrient demand:				
N	20.1	kg/du	calculated	
P	4.0	kg/du	calculated	
K	23.5	kg/du	calculated	
Nutrients in water:				
N	7.1	kg/du	calculated	
P	1.2	kg/du	calculated	
K	10.0	kg/du	calculated	
Manure application:				
N	2.4	kg/du	calculated	
P	2.1	kg/du	calculated	
K	6.3	kg/du	calculated	
Nutrients in soil:				
N	8.9	kg/du	calculated	
P	5.8	kg/du	calculated	
K	72.1	kg/du	calculated	
Fertilizer application:				
N	78.4	kg/du	calculated	
P	33.7	kg/du	calculated	
K	237.1	kg/du	calculated	

Crop water requirement:

For calculating crop water requirement, ET_o,K_c, length of each cropping stage and crop cover estimates are required.

ET_o from Table 6: Weather station

Karamah

Month	ET_0 /day	ET_0 /week	weeks of vegetation
September	4.85	34.0	0.7
October	3.29	23.0	4.4
November	1.93	13.5	4.3
December	1.33	9.3	4.4
January	1.38	9.7	4.4
February	1.92	13.4	4.1
March	2.98	20.9	2.6

Vegetation period 175 days = 25 weeks

K_c- Factor from Table 7 Crop

Tomato

	K_c factor	days	weeks
K_{c1}	0.6	22	3.1
K_{c2}	0.93	30	4.3
K_{c3}	1.25	93	13.3
K_{c4}	0.65	30	4.3

adjust days in Table 7 according to your cultivation scheme

Crop coefficient approach

Equation 1 **ET_c (mm/week) = K_c * ET_o (mm/week)**

Equation 4 **FWR (mm/week) = ET_c * 1.33 * 1.1 *0.8**

Calculate own table:

Week	K_c factor	ET_0 (mm/week)	ET_c (mm/week)	FWR (mm/week)
1	0.4	34.0	13.6	15.9
2	0.5	23.0	11.5	13.5
3	0.6	23.0	13.8	16.2
4	0.7	23.0	16.1	18.9
5	0.8	23.0	18.4	21.6
6	0.9	13.5	12.2	14.2
7	0.9	13.5	12.6	14.7
8	1.0	13.5	13.5	15.8
9	1.1	13.5	14.9	17.4
10	1.1	9.3	10.2	12.0
11	1.2	9.3	11.2	13.1
12	1.3	9.3	11.6	13.6
13	1.3	9.3	11.6	13.6
14	1.3	9.7	12.1	14.1
15	1.3	9.7	12.1	14.1
16	1.2	9.7	11.6	13.6
17	1.2	9.7	11.1	13.0
18	1.1	13.4	14.8	17.3
19	1.0	13.4	13.4	15.7
20	0.9	13.4	12.1	14.2
21	0.8	13.4	10.8	12.6
22	0.7	20.9	13.6	15.9
23	0.7	20.9	13.6	15.9
24	0.7	20.9	13.6	15.9
25	0.6	20.9	12.5	14.6
Total			**322.4**	**377.3**

Dynamic approach (weekly changing factors)

Ground coverage approach

Equation **ET_c (mm/week) = ground coverage (%) * 1.2 * ET_o (mm/week)**

Equation 4 **FWR (mm/week) = ET_c * 1.33 * 1.1 * 0.8**

Calculate own table:

Week	Ground coverage (%)	ET_0 (mm/week)	Factor 1.2	ET_c (mm/week)	FWR (mm/week)
1	0.2	34.0	1.2	8.1	9.5
2	0.3	23.0	1.2	8.3	9.7
3	0.4	23.0	1.2	11.1	12.9
4	0.5	23.0	1.2	13.8	16.2
5	0.6	23.0	1.2	16.6	19.4
6	0.7	13.5	1.2	11.3	13.3
7	0.8	13.5	1.2	13.0	15.2
8	0.9	13.5	1.2	14.6	17.1
9	1.0	13.5	1.2	16.2	19.0
10	1.0	9.3	1.2	11.2	13.1
11	1.0	9.3	1.2	11.2	13.1
12	1.0	9.3	1.2	11.2	13.1
13	1.0	9.3	1.2	11.2	13.1
14	1.0	9.7	1.2	11.6	13.6
15	1.0	9.7	1.2	11.6	13.6
16	1.0	9.7	1.2	11.6	13.6
17	1.0	9.7	1.2	11.6	13.6
18	1.0	13.4	1.2	16.1	18.9
19	1.0	13.4	1.2	16.1	18.9
20	0.9	13.4	1.2	14.5	17.0
21	0.8	13.4	1.2	12.9	15.1
22	0.7	20.9	1.2	16.3	19.0
23	0.7	20.9	1.2	16.3	19.0
24	0.7	20.9	1.2	16.3	19.0
25	0.6	20.9	1.2	15.0	17.6
Total				**327.6**	**383.4**

Dynamic approach (weekly changing coverage)

Pre-irrigation requirement:

For estimating pre-irrigation requirement, soil type and EC_{soil} are required.

Loam 4.06

From Table 9:
First fill up to water content at field capacity (81 mm) and then irrigate 15 mm = total 96 mm for a leaching depth to 0.3 m.

Net and gross irrigation depth (mm)

For estimating net irrigation depth, soil type and row spacing are required.

Loam ← → 1.6 m

Table 10:	Net depth for loam (mm)			
	0.15 m	0.3 m	0.5 m	0.7 m
Net water depth:	6.3	12.6	21	29.4

Equation 12: Gross water depth (mm) = Net water depth (mm) * 1.48

Calculate own table:	Gross depth for loam (mm)			
	0.15 m	0.3 m	0.5 m	0.7 m
Gross water depth:	9.3	18.6	31.1	43.5

Application rate (mm) and running time (mm/h)

For calculating **application rate**, emitter flow rate, emitter spacing and row spacing are required.

↓ 4 l/h ↓ 0.4 m ↓ 1.6 m

Equation 13: Application rate (mm/h) = $\frac{\textbf{Emitter flow rate (mm/h)}}{\textbf{Emitter spacing (m) * row spacing (m)}}$

Calculated application rate = 6.3 mm/h

For calculating **running time**, water depth and application rate are required

↙ 13.6 mm, week 16 ↓ 6.3 mm/h

Equation 14: Running time (h) = $\frac{\textbf{Water depth (mm)}}{\textbf{Application rate (mm/h)}}$

Running time: 2.2 h

Application rate (mm) versus infiltration rate (mm)

To see wether soil can take up the applied water, application and infiltration rates should be compared. Soil type is required.

↓ Loam ↓ 6.3 mm/h

From Table 11:	Infiltration rate (mm/h)
Loam	11 mm/h

Infiltration rate (11 mm/h) is higher than application rate (6.3 mm/h), no problems will occur.

Irrigation frequency

Calculated gross water depths are in most cases higher than FWR, that means that there is no need to irrigate several times a week.

Example:	FWR, week 21, cover approach:	15.1 mm
	Gross water depth, 0.7 m:	87.0 mm

FWR is lower than GWD, the amount can be applied at once in one week,

Crop nutrient requirement:

For calculating crop nutrient requirement, expected yield and crop are required

↓ ↓

6.7 t/du tomato

Equation 15: Crop nutrient requirement (kg/du) = expected yield (t/du) * nutrient removal (kg/t)

From Table 21:	Removal of nutrients (kg/t produce), tomato, IFA mean
N	3 kg/t
P	0.6 kg/t
K	3.5 kg/t

Calculate own Table:	Nutrient requirement (kg/du)
N	20.1 kg/du
P	4.02 kg/du
K	23.45 kg/du

Amount of nutrients in irrigation water

For calculating nutrients in irrigation water, water source, nutrient contents in irrigation water and field water requirement (m³/du) are required

↘ KAC

→ 383 mm (coverage approach) = 383 m³/du

Equation: Amount of nutrient (kg/du) =

$$\frac{\textbf{Amount of irrigation water (m}^3\textbf{) * Amount of nutrient in irrigation water (mg/l)}}{\textbf{1000}}$$

From Table 22:	Nutrients in RW (mg/l)
N	18.4 mg/l
P	3.1 mg/l
K	26 mg/l

Calculate own Table:	Nutrients in RW (kg/du)
N	7.1 kg/du
P	1.2 kg/du
K	10.0 kg/du

Amount of nutrients in manure

For calculating nutrients in manure, manure type, nutrient contents and availability and application amount are required

chicken

1250 kg/du

Equation: Amount of nutrient (kg/du) =

$$\frac{\textbf{Manure amount (kg/du) * Nutrient available first year (\%) * (1-(\%) nutrient loss) * nutrient content (\%) in manure}}{\textbf{100}}$$

From Table 23 and 24, poultry manure:	Manure contribution (%) content	(%) available in first year	(%) loss
N	0.9	0.7	0.3-0.7
P	0.22	0.9	0.15
K	0.66	0.9	0.15

Calculate own Table:	Nutrient amount in manure (kg/du)
N	2.4 kg/du
P	2.1 kg/du
K	6.3 kg/du

Amount of nutrients in soil

For calculating nutrients in soil, soil analyses data are required

N = 0.16% P = 193 ppm K = 502 ppm Loam

Equation16 : Amount of N (kg/du) =

$$\frac{\textbf{N (\%) *soil bulk density (kg/m}^3\textbf{) * area (m}^2\textbf{) * soil depth (m) * N-mineralisation factor * N correction factor * wetting (\%)}}{\textbf{100}}$$

Equation18/20 : Amount of P or K (kg/du) =

$$\frac{\textbf{P or K (ppm) *soil bulk density (kg/m}^3\textbf{) * soil depth (m) * P or K correction factor * wetting (\%)}}{\textbf{1000}}$$

From Table 27: Soil bulk density = 1400 kg/m³

Calculate own Table:	Nutrient amount (kg/du)
N	8.9 kg/du
P	5.8 kg/du
K	72.1 kg/du

Amount of nutrients to fertilize

For calculating nutrients to fertilize, subtract nutrients in irrigation water, nutrients in manure and nutrients in soil from crop nutrient requirement

Equation: Amount of nutrient to fertilise (kg/du) = crop nutrient requirement (kg/du) - nutrients in water (kg/du) - nutrients in manure (kg/du) - nutrients in soil (kg/du)

Calculate own Table:	CNR (kg/du)
N	1.8
P	-5.1
K	-64.9

No need to fertilise P and K !!

Fertilizer requirement:

For calculating fertilizer requirement, CNR and distribution uniformity (75%) are required.

In the example one can see that there is no need to fertilize P and K, because it is already present in high amounts in soil, manure and water. (Resulting in negative values for CNR). To calculate an example nonetheless, fertilisation amounts for P and K are assumed to be positive and N-requirement is assumed to be the 22-fold of the actual requirement .

Calculate own Table:	CNR (kg/du)	fertilizer requirement (kg/du)
N	40.0	53.3
P	5.1	6.8
K	64.9	86.6

÷ 75%

46%

Equation 24: Amount of P fertilizer (kg/du) = $\frac{\text{Amount of P fertilizer requirement * 100}}{\text{\% P in fertilizer * 0.44}}$

Equation 23: Amount of K fertilizer (kg/du) = $\frac{\text{Amount of K fertilizer requirement * 100}}{\text{\% K in fertilizer * 0.83}}$

44%

Amount of P fertilizer (DAP):	33.7 kg/du
Amount of K fertilizer (KNO_3):	237.1 kg/du

The next step is to calculate the amount of N in both fertilizers (DAP and KNO_3).

Equation: Amount of N in P fertilizer (kg/du) = Amount of P fertilizer * (%) N in P fertilizer

Equation: Amount of N in K fertilizer (kg/du) = Amount of K fertilizer * (%) N in K fertilizer

Amount of N in P fertilizer:	6.1 kg/du
Amount of N in K fertilizer:	30.8 kg/du

The next step is to calculate the amount of N which still has to be fertilised

Equation: Amount of N fertilizer (kg/du) =
N-fertilizer requirement (kg/du) - N in P fertilizer (kg/du) - N in K fertilizer (kg/du)

Amount of N still required:	16.5 kg/du

The next step is to calculate the amount of N in the fertilizer

21%

Equation22: Amount of N fertilizer (kg/du) = $\frac{\text{Amount of N fertilizer requirement * 100}}{\text{\% N in fertilizer}}$

Amount of N fertilizer: (AS)	78.4 kg/du

Weekly fertilizer requirement:

For calculating weekly fertilizer requirement, fertilizer amount and length of the different crop stages are required.

Equation 25: Amount of fertilizer/week (kg/du) =

$$\frac{\text{(Amount of fertilizer (kg/du) * (nutrient uptake for relevant stage (\%)) * 7}}{\text{Length of relevant stage (d)}}$$

From Table 30:	Percentages of nutrient uptake during different growth stages			
	Vegetative	Flowering& fruiting	Ripening & harvesting	Senes-cence
Nutrient uptake (%)	0.15	0.25	0.55	0.05

Calculate own Table:	Amount of fertilizer/week (kg/du)			
	Vegetative	Flowering& fruiting	Ripening & harvesting	Senes-cence
N-fertilizer	3.7	4.6	3.2	0.9
P-fertilizer	1.6	2.0	1.4	0.4
K-fertilizer	11.3	13.8	9.8	2.8

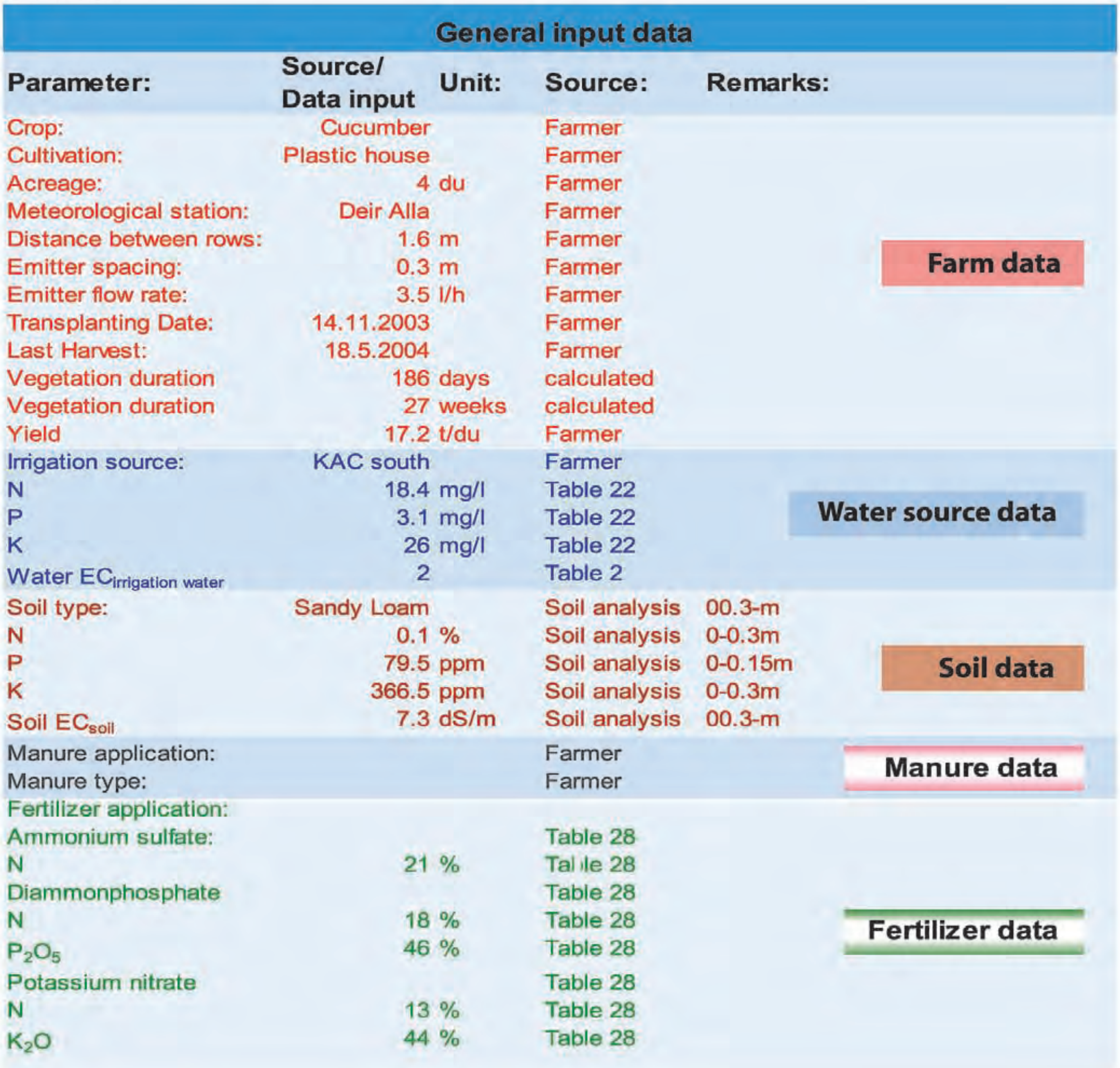
Sufficiency level concept:

To estimate whether there are enough nutrients in the regarded soil to sustain a certain crop, Table 32 should be consulted. Tabulated values are given for a depth of 0.3 m

From Table 32:	Tomato, heavy feeder, fine textured soil		
	ppm Table	ppm Soil	
P	114	96	no fertilisation (value is for 0-0.15 m)
K	249	502	no fertilisation

11.6 Example Calculation for Cucumber in Plastic House

Cucumber



General input data					
Parameter:	**Source/ Data input**	**Unit:**	**Source:**	**Remarks:**	
Crop:	Cucumber		Farmer		
Cultivation:	Plastic house		Farmer		
Acreage:	4	du	Farmer		
Meteorological station:	Deir Alla		Farmer		
Distance between rows:	1.6	m	Farmer		
Emitter spacing:	0.3	m	Farmer		**Farm data**
Emitter flow rate:	3.5	l/h	Farmer		
Transplanting Date:	14.11.2003		Farmer		
Last Harvest:	18.5.2004		Farmer		
Vegetation duration	186	days	calculated		
Vegetation duration	27	weeks	calculated		
Yield	17.2	t/du	Farmer		
Irrigation source:	KAC south		Farmer		
N	18.4	mg/l	Table 22		
P	3.1	mg/l	Table 22		**Water source data**
K	26	mg/l	Table 22		
Water $EC_{irrigation\ water}$	2		Table 2		
Soil type:	Sandy Loam		Soil analysis	00.3-m	
N	0.1	%	Soil analysis	0-0.3m	
P	79.5	ppm	Soil analysis	0-0.15m	**Soil data**
K	366.5	ppm	Soil analysis	0-0.3m	
Soil EC_{soil}	7.3	dS/m	Soil analysis	00.3-m	
Manure application:			Farmer		**Manure data**
Manure type:			Farmer		
Fertilizer application:					
Ammonium sulfate:			Table 28		
N	21	%	Table 28		
Diammonphosphate			Table 28		
N	18	%	Table 28		**Fertilizer data**
P_2O_5	46	%	Table 28		
Potassium nitrate			Table 28		
N	13	%	Table 28		
K_2O	44	%	Table 28		

Calculating guideline data				
Parameter:		**Unit:**	**Source:**	**Remarks:**
Crop water requirement coverage approach:	543	mm	calculated	
Field water requirement coverage approach:	673	mm	calculated	
Crop water requirement Kc approach:	695	mm	calculated	
Field water requirement Kc approach:	561	mm	calculated	
Net depth:	3.1	mm	Table 10	
Gross depth: 015- cm	4.6	mm	calculated	lower than highest weekly FWR, application should be splitted, twice/thrice a week
Gross depth: 030- cm	9.2	mm	calculated	lower than highest weekly FWR, application should be splitted, twice/thrice a week
Gross depth: 050- cm	15.3	mm	calculated	lower than highest weekly FWR, application should be splitted, twice/thrice a week
Gross depth: 070- cm	21.4	mm	calculated	lower than highest weekly FWR, application should be splitted, twice/thrice a week
Infiltration rate:	13.0	mm/h	Table 11	
Application rate:	7.3	mm/h	calculated	
Pre-irrigation requirement	85	mm	Table 9	Sandy loam 0.3 m
Crop nutrient demand:				
N	20.1	kg/du	calculated	
P	4.0	kg/du	calculated	
K	23.5	kg/du	calculated	
Nutrients in water:				
N	7.1	kg/du	calculated	
P	1.2	kg/du	calculated	
K	10.0	kg/du	calculated	
Manure application:				
N	2.4	kg/du	calculated	
P	2.1	kg/du	calculated	
K	6.3	kg/du	calculated	
Nutrients in soil:				
N	8.9	kg/du	calculated	
P	5.8	kg/du	calculated	
K	72.1	kg/du	calculated	
Fertilizer application:				
N	0.0	kg/du	calculated	
P	0.0	kg/du	calculated	
K	0.0	kg/du	calculated	

Crop water requirement:

For calculating crop water requirement, ET_o, K_c, length of each cropping stage and crop cover estimates are required.

ET_o from Table 6:

Weather station

Deir Allah

Month	ET_0/day	ET_0/week	weeks of vegetation
November	4	28.0	2.42
December	2.66	18.6	4.42
January	2.51	17.6	4.42
February	2.8	19.6	4.1
March	3.8	26.6	4.42
April	5.58	39.1	4.28
May	6.93	48.5	2.57

Vegetation period
187 days = 27 weeks

K_c- Factor from Table 7

Crop

Cucumber

	K_c factor	days	weeks
K_{c1}	0.6	28	4.1
K_{c2}	0.87	34	4.9
K_{c3}	1.15	87	12.6
K_{c4}	0.75	38	5.5

adjust days in Table 7 according to your cultivation scheme

Crop coefficient approach "Greenhouse" in DA 23

Equation 1 $ET_c \text{ (mm/week)} = K_c * ET_o \text{ (mm/week)}$

Equation 8 $FWR \text{ (mm/week)} = ET_c * 1.33 * 1.15 * 1.1 * 0.8 * 0.6$

Calculate own table:

Week	K_c factor	ET_0 (mm/week)	ET_c (mm/week)	FWR (mm/week)
1	0.4	28	11.2	9.0
2	0.5	28	14.0	11.3
3	0.6	28	16.8	13.6
4	0.7	18.6	13.0	10.5
5	0.8	18.6	14.9	12.0
6	0.9	18.6	16.8	13.5
7	0.9	18.6	17.3	14.0
8	1.0	17.6	17.6	14.2
9	1.1	17.6	19.3	15.6
10	1.1	17.6	19.3	15.6
11	1.2	17.6	20.2	16.3
12	1.2	19.6	22.5	18.2
13	1.2	19.6	22.5	18.2
14	1.2	19.6	22.5	18.2
15	1.2	19.6	22.5	18.2
16	1.2	26.6	30.6	24.7
17	1.1	26.6	29.3	23.6
18	1.1	26.6	29.3	23.6
19	1.1	26.6	29.3	23.6
20	1.1	39.1	43.0	34.7
21	1.1	39.1	41.0	33.1
22	1.0	39.1	39.1	31.5
23	0.9	39.1	35.2	28.4
24	0.8	48.5	38.8	31.3
25	0.8	48.5	36.4	29.4
26	0.8	48.5	36.4	29.4
27	0.8	48.5	36.4	29.4
Total			**695**	**561**

Dynamic approach (weekly changing factors)

Ground coverage approach "Greenhouse" in DA23

Equation **ET_c (mm/week) = ground coverage (%) * 1.2 * ET_o (mm/week)**

Equation 8 **FWR (mm/week) = ET_c * 1.33 * 1.15 * 1.1 *0.8 * 0.6**

Calculate own table:

Week	Ground coverage (%)	ET_0 (mm/week)	ETc (mm/week)	FWR (mm/week)
1	0.2	28	6.7	5.4
2	0.3	28	10.1	8.1
3	0.4	28	13.4	10.9
4	0.5	18.6	11.2	9.0
5	0.6	18.6	13.4	10.8
6	0.7	18.6	15.6	12.6
7	0.8	18.6	17.9	14.4
8	0.9	17.6	19.0	15.3
9	1.0	17.6	21.1	17.0
10	1.0	17.6	21.1	17.0
11	1.0	17.6	21.1	17.0
12	1.0	19.6	23.5	19.0
13	1.0	19.6	23.5	19.0
14	1.0	19.6	23.5	19.0
15	1.0	19.6	23.5	19.0
16	1.0	26.6	31.9	25.8
17	1.0	26.6	31.9	25.8
18	1.0	26.6	31.9	25.8
19	1.0	26.6	31.9	25.8
20	0.9	39.1	42.2	34.1
21	0.8	39.1	37.5	30.3
22	0.7	39.1	30.5	24.6
23	0.7	39.1	30.5	24.6
24	0.7	48.5	37.8	30.6
25	0.6	48.5	34.9	28.2
26	0.6	48.5	34.9	28.2
27	0.6	48.5	32.0	25.9
Total			**672.6**	**543.2**

Dynamic approach (weekly changing coverage)

Pre-irrigation requirement:

For estimating pre-irrigation requirement, soil type and EC_{soil} are required.

Sandy loam 7.3

From Table 9:

First fill up to water content at field capacity (62 mm) and then irrigate approximately 85 mm for a leaching depth to 0.3 m.

Net and gross irrigation depth (mm)

For estimating net irrigation depth, soil type and row spacing are required.

Sandy loam 1.6 m

Table 10:	Net depth for loam (mm)			
	0.15 m	0.3 m	0.5 m	0.7 m
Net water depth:	3.0	6.1	10.1	14.2

Equation 12 : Gross water depth (mm) = Net water depth (mm) * 1.48

Calculate own table:	Gross depth for loam (mm)			
	0.15 m	0.3 m	0.5 m	0.7 m
Gross water depth:	4.5	9.0	15.0	21.0

Application rate (mm) and running time (mm/h)

For calculating **application rate**, emitter flow rate, emitter spacing and row spacing are required.

3.5 l/h 0.3 m 1.6 m

Equation 13 :

$$\text{Application rate (mm/h)} = \frac{\text{Emitter flow rate (mm/h)}}{\text{Emitter spacing (m)} * \text{row spacing (m)}}$$

Calculated application rate = 7.3 mm/h

For calculating **running time**, water depth and application rate are required

Coverage approach 25.8 mm, week 16 7.3 mm/h

Equation 14:

$$\text{Running time (h)} = \frac{\text{Water depth (mm)}}{\text{Application rate (mm/h)}}$$

Running time: 3.5 h

Application rate (mm) versus infiltration rate (mm)

To see wether soil can take up the applied water, application and infiltration rates should be compared. Soil type is required.

7.3 mm/h

Sandy loam

From Table 11:	Infiltration rate (mm/h)	
Sandy loam	13	mm/h

Infiltration rate (13 mm/h) is higher than application rate (7.3 mm/h), no problems will occur.

Irrigation frequency

Calculated gross water depths are on most cases lower than FWR, that means that there is a need to irrigate several times a week.

Example:	FWR, week 21, cover approach:	30.3 mm
	Gross water depth, 0.7 m:	21.4 mm

FWR is higher than GWD, the amount should not be applied as whole in one week, but daily, because daily FWR = 30 mm /7 days = 4.3 mm/day

Crop nutrient requirement:

For calculating crop nutrient requirement, expected yield and crop are required

17.2 t/du cucumber

Equation 15: Crop nutrient requirement (kg/du) = expected yield (t/du) * nutrient removal (kg/t)

From Table 21:	Removal of nutrients (kg/t produce), cucumber, IFA mean
N	3 kg/t
P	0.6 kg/t
K	3 kg/t

Calculate own Table:	Nutrient requirement (kg/du)
N	51.6 kg/du
P	10.3 kg/du
K	51.6 kg/du

Amount of nutrients in irrigation water

For calculating nutrients in irrigation water, water source, nutrient contents in irrigation water and field water requirement (m^3/du) are required KAC south

383 mm (coverage approach) = 383 m^3/du

Equation: Amount of nutrient (kg/du) =

$$\frac{\textbf{Amount of irrigation water (m}^3\textbf{) * Amount of nutrient in irrigation water (mg/l)}}{\textbf{1000}}$$

From Table 22:	Nutrients in RW (mg/l)
N	18.4 mg/l
P	3.1 mg/l
K	26 mg/l

Calculate own Table:	Nutrients in RW (kg/du)
N	12.4 kg/du
P	2.1 kg/du
K	17.5 kg/du

Amount of nutrients in manure

For calculating nutrients in manure, manure type, nutrient contents and availability and application amount are required

no manure

Amount of nutrients in soil

For calculating nutrients in soil, soil analyses data are required

N = 0.10% P = 159 ppm K = 367 ppm Sandy loam

Equation 16: Amount of N (kg/du) =

$$\frac{\text{N (\%) * soil bulk density (kg/m}^3\text{) * area (m}^2\text{) * soil depth (m) * N-mineralisation factor * N correction factor * wetting (\%)}}{100}$$

Equation 18/20: Amount of P or K (kg/du) =

$$\frac{\text{P or K (ppm) * soil bulk density (kg/m}^3\text{) * soil depth (m) * P or K correction factor * wetting (\%)}}{1000}$$

From Table 27: Soil bulk density = 1500 kg/m³

Calculate own Table:	Nutrient amount (kg/du)
N	5.9 kg/du
P	10.3 kg/du
K	56.4 kg/du

Amount of nutrients to fertilize

For calculating nutrients to fertilize, subtract nutrients in irrigation water, nutrients in manure and nutrients in soil from crop nutrient requirement

Equation: Amount of nutrient to fertilise (kg/du) = crop nutrient requirement (kg/du) - nutrients in water (kg/du) - nutrients in manure (kg/du) - nutrients in soil (kg/du)

Calculate own Table:	CNR (kg/du)
N	33.3
P	-2.1
K	-22.3

Fertilizer requirement:

For calculating fertilizer requirement, CNR and distribution uniformity (75%) are required.

In the example one can see that there is no need to fertilize P and K, because it is already present in high amounts in soil and water. (Resulting in negative values for CNR). To calculate an example nonetheless, fertilisation amounts for P and K are assumed to be positive.

Calculate own Table:	CNR (kg/du)		fertilizer requirement (kg/du)
N	33.3	÷75%	44.4
P	2.1		2.8
K	22.3		29.7

46%

Equation 23: Amount of P fertilizer (kg/du) $\frac{\textbf{Amount of P fertilizer requirement * 100}}{\textbf{\% P in fertilizer * 0.44}}$

Equation 24: Amount of K fertilizer (kg/du) $\frac{\textbf{Amount of K fertilizer requirement * 100}}{\textbf{\% K in fertilizer * 0.83}}$

44%

Amount of P fertilizer (DAP):	13.6 kg/du
Amount of K fertilizer (KNO_3):	81.4 kg/du

The next step is to calculate the amount of N in both fertilizers (DAP and KNO_3).

Equation: Amount of N in P fertilizer (kg/du) = Amount of P fertilizer * (%) N in P fertilizer

Equation: Amount of N in K fertilizer (kg/du) = Amount of K fertilizer * (%) N in K fertilizer

Amount of N in P fertilizer:	2.5 kg/du
Amount of N in K fertilizer:	10.6 kg/du

The next step is to calculate the amount of N which still has to be fertilised

Equation: Amount of N fertilizer (kg/du) =
N-fertilizer requirement (kg/du) - N in P fertilizer (kg/du) - N in K fertilizer (kg/du)

Amount of N still required: 31.3 kg/du

The next step is to calculate the amount of N in the fertilizer

21%

Equation 22: Amount of N fertilizer (kg/du) $\frac{\textbf{Amount of N fertilizer requirement * 100}}{\textbf{\% N in fertilizer}}$

Amount of N fertilizer (AS): 149.3 kg/du

Weekly fertilizer requirement:

For calculating weekly fertilizer requirement, fertilizer amount and length of the different crop stages are required.

Equation 25: Amount of fertilizer/week (kg/du) =

$$\frac{\text{(Amount of fertilizer (kg/du) * (nutrient uptake for relevant stage (\%)) * 7}}{\text{Length of relevant stage (d)}}$$

From Table 30:	Percentages of nutrient uptake during different growth stages			
	Vegetative	Flowering& fruiting	Ripening & harvesting	Senes-cence
Nutrient uptake (%)	0.15	0.25	0.55	0.05

Calculate own Table:	Amount of fertilizer/week (kg/du)			
	Vegetative	Flowering& fruiting	Ripening & harvesting	Senes-cence
N-fertilizer	5.6	7.7	6.6	1.4
P-fertilizer	0.5	0.7	0.6	0.1
K-fertilizer	3.1	4.2	3.6	0.7

Sufficiency level concept:

To estimate whether there are enough nutrients in the regarded soil to sustain a certain crop, Table 32 should be consulted. Tabulated values are given for a depth of 0.3 m

From Table 32:	Cucumber, very heavy feeder, medium textured soil, yield more than 10 t/du		
	ppm Table	ppm Soil	
P	158	80	fertilisation should be kept at an absolut minimum (value is for 0-0.15m)
K	562	367	fertilisation required

Imprint

These guidelines were prepared by
Sameer Abdel-Jabbar

in cooperation with
Artur Vallentin and Dr. Marion Boening-Zilkens

Project coordinators
Nayef Seder, JVA
Artur Vallentin, GTZ

We are sure that additional experiences and knowledge about the use of reclaimed water under comparable environmental conditions exist. Therefore comments and feedback are highly appreciated. Please contact

Sameer Abdel-Jabbar
Reclaimed Water Project
P.O.Box 926 238
Amman 11190, Jordan
Email: sameer.jabbar@gtz.jo
Mobile:+962 79 5519381

Irrigation