INTERNATIONAL STANDARD

ISO 16075-6

First edition
2023-12

Guidelines for treated wastewater use for irrigation projects —

Part 6:
Fertilization

Lignes directrices pour l'utilisation des eaux usées traitées en irrigation —

Partie 6: Fertilisation

Reference number
ISO 16075-6:2023(E)

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

ISO draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO had not received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at www.iso.org/patents. ISO shall not be held responsible for identifying any or all such patent rights.

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 282, *Water reuse*, Subcommittee SC 1, *Treated wastewater reuse for irrigation*.

A list of all parts in the ISO 16075 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Treated wastewater (TWW) contains nutrients that are essential for the proper development of various crops irrigated with it, but can also have a detrimental effect on crops, soil, natural water sources and the environment in general.

There are several reasons why it is critical to optimize TWW and additional amendments (e.g. manure, sludge, synthetic fertilizers):

— Using excessive quantities is costly and wasteful.

— Leaching excess nutrients that the crops do not utilize can pollute groundwater and add additional treatment costs and health risks to drinking water supplies.

— Climate change phenomena that cause drought or storm cycles can overwhelm infiltration capacity and runoff to pollute streams and waterways.

— Phosphorus excess in diffuse or point source runoff causes eutrophication of water bodies and upsets the balance in wetlands and other valuable environmental resources.

— Current scientific knowledge, as provided in this document, enables users to balance nutrients and forecast their impact more accurately to enhance crops and their profitability.

Thus, it is very important to create a plan of the types and amounts of fertilizers that should be added to various crops, taking into account the amounts of nutrients that already exist in the TWW that is used to irrigate the crops.

The concentration of nutrients found in TWW depends, among other things, on the source of the wastewaters and on the level of treatment given to the wastewater, with concentration decreasing at each stage, in the initial, secondary, tertiary and advanced treatment stages.

The fertilization plans of the various crops should take into consideration the nutritional value found in TWW, with awareness that, along with the positive contribution of the nutrients in TWW, there are other aspects that should be considered when developing the fertilization plans, such as:

— the total amount of each nutrient applied during an irrigation season;

— synchronization between nutrient application with TWW irrigation and crop needs;

— availability of nutrients to the crops according to the chemical forms existing in TWW, in comparison with nutrient availability in inorganic fertilizers.

Understanding all these factors will contribute to reducing or eliminating the negative effects that excess nutrients can produce on soils, crops, natural water sources and the environment, adjusting or reducing the amounts of nutrients supplied to the various crops by inorganic fertilizers. The fertilization programme should also take into account nitrogen and phosphorus from other sources that crops can use, such as soil or crop residue.

Guidelines for treated wastewater use for irrigation projects —

Part 6:
Fertilization

1 Scope

This document provides guidelines for the evaluation of the fertilizer value of treated wastewater (TWW) at different treatment levels, for an effective fertilization of crops irrigated with TWW. This document covers:

— evaluation of the nutrient quantities provided by TWW and the synchronization between crop needs and the nutrients applied with TWW;

— availability of nutrients to crops irrigated with TWW;

— monitoring nutrients in water, soil and crops irrigated with TWW;

— matching between TWW quality and fertilizer properties.

Risk assessment and risk management for the safe use of TWW in irrigation projects are addressed in ISO 20426[1] and ISO 16075-2[2].

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 20670, *Water reuse — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 20670 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
denitrification
reduction of nitrate and/or nitrite to nitrogen or dinitrogen monoxide, usually by the action of bacteria

[SOURCE: ISO 6107:2021, 3.160[3]]

3.2
micronutrients
elements which are required by plants in only very small amounts

Note 1 to entry: Although these are present in plants at very low rates, such macronutrients as nitrogen and potassium, they are essential for normal plant growth.

3.3
nitrification
oxidation of ammonium compounds by bacteria

Note 1 to entry: Usually the intermediate product is nitrite and the end product nitrate.

[SOURCE: ISO 6107:2021, 3.359[3]]

3.1.4
macronutrients
elements which are required by plants in the largest amount (nitrogen, phosphorus and potassium)

4 Source of macronutrients and trace elements in TWW

4.1 General

Sources of macronutrients and micronutrients in TWW should be evaluated in order to take advantage of these nutrients in the fertilization programme of the crops, with a view to partially replacing the fertilizers and avoiding damage that excesses could cause to crops, soils and water resources.

The amount of nitrogen and phosphorus to be supplied to the crop is calculated using the nitrogen and phosphorus fertilization balance.

4.2 Nitrogen (N)

The main sources of nitrogen in municipal wastewater are faeces (about 20 % of the nitrogen in municipal wastewater), urine (about 75 % of the nitrogen in municipal wastewater) and food scraps. These sources contribute between 3,5 kg and 6,9 kg of nitrogen per capita per year (about 40 % as ammonium and about 60 % as organic nitrogen).[4,5] In raw wastewater, nitrogen appears mainly as ammonium and organic nitrogen (soluble or suspended). In the soluble fraction, most of the nitrogen is found in urea or amino acids and in the suspended fraction – in proteins – and the nitrate-nitrogen concentration is very low. When the organic load is higher than is common in municipal wastewater, such as dairy or food industry wastewater, the overall nitrogen concentration can reach much higher values.

The range of nitrogen concentration in raw municipal wastewater is wide, depending on water use per capita, from 20 mg l^{-1} to 70 mg l^{-1} total nitrogen with a typical concentration of 40 mg l^{-1}. The organic nitrogen is in the range 8 mg l^{-1} to 25 mg l^{-1} and the ammonium is in the range 12 mg l^{-1} to 45 mg l^{-1}.[6]

However, it should be taken into account that not all the nitrogen forms (such as organic nitrogen) present in the TWW will be immediately available to the crops.

4.3 Phosphorus (P)

The predominant phosphorus sources in wastewaters are human excretion and detergents. These sources contribute, respectively, with 1,5 g and 0,4 g of phosphorus per day per person.[7] Raw wastewater contains inorganic and organic bound phosphorus.

The range of total phosphorus concentration in raw municipal wastewater is wide, from 4 mg l^{-1} to 12 mg l^{-1}, with a typical concentration of 7 mg l^{-1}.[6]

Higher concentrations can be observed when the treatment plant receives industrial wastewater and/or wastewater from animal husbandry.

The inorganic phosphorus content in raw municipal wastewater is in the range 3 mg l^{-1} to 10 mg l^{-1}, with a typical concentration of 5 mg l^{-1}; the organic phosphorus content is in the range 1 mg l^{-1} to 4 mg l^{-1}, with a typical concentration of 2 mg l^{-1}.[6–8]

However, it should be taken into account that not all the phosphorus forms present in the TWW will be immediately available to the crops, as they absorb this nutrient in the inorganic form.

4.4 Potassium (K)

Three main sources of potassium in TWW are known. The main source is human urine excreted with municipal wastewater (20 mg l^{-1} to 170 mg l^{-1} of potassium). Other sources are animal excrement and industrial wastewater in factories where sodium salts have been replaced by potassium in water-softening systems. The range of potassium content in raw municipal wastewater is wide, from 5 mg l^{-1} to 25 mg l^{-1}.[9]

4.5 Trace elements

The main sources of trace elements in wastewater are freshwater and any additions from domestic, industrial and agricultural water use. Trace elements are widely used in industries such as metal coating, batteries, animal hide processing, the chemical industry, the textile industry and the electronics industry. Corrosion of water pipes is also a source of trace elements.

The range of trace elements content in raw municipal wastewater is wide, depending on the proportion of industrial wastewater flowing to the treatment plant.

Some of these trace elements are also essential micronutrients for crops. This document covers the role of trace elements as micronutrients for crops and not their possible toxic effect on crops or their entry into the food chain. These deleterious effects are presented in ISO 16075-1.[10]

The concentration range in TWW for several trace elements is presented in Table 1.

Table 1 — Concentration of trace elements in raw wastewater and removal by wastewater treatment[a]

Element	Range mg l^{-1}	Removal range according to the level of treatment (primary to tertiary) %
Arsenic (As)	< 0,000 3 to 1,9	3 to 52
Boron (B)	< 0,123 to 20,0	0 to 13
Cadmium (Cd)	< 0,001 2 to 2,1	17 to 84
Chromium (Cr)	< 0,000 8 to 83,3	0 to 85
Copper (Cu)	< 0,000 1 to 36,5	0 to 84
Lead (Pb)	0,001 to 11,6	0 to 93
Mercury (Hg)	< 0,000 1 to 3,0	33
Nickel (Ni)	0,002 to 111,4	0 to 44
Zinc (Zn)	< 0,001 to 28,7	6 to 97

NOTE Values are indicative since wastewater composition can change over time and by location.

[a] Modified from References [6] and [11].

5 Concentration of macronutrients at various levels of wastewater treatment

The concentration of nitrogen and phosphorus in TWW decreases according to the treatment level: primary, secondary, tertiary or any specific treatment to remove N and P. Table 2 presents comparative data on the concentrations of nitrogen and phosphorus at different treatment levels.

Each stage of treatment reduces nitrogen and phosphorus through the removal of organic matter by sedimentation or biological treatment. Further removal of nitrogen and phosphorus can be performed by dedicated treatments.

NOTE Agricultural use of TWW requires storage in order to balance the flows between TWW production and its consumption. During storage, both elements will decrease, depending on the initial concentrations at the entrance to the reservoir and the corresponding retention time. The initial concentration depends on the biological wastewater treatment efficiency, and that is affected by temperature. Thus, the nutrient concentrations in TWW treated biologically fluctuates seasonally in regions with high temperature variations.

Table 2 shows that TWW with more intensive treatments than activated sludge, such as activated sludge with biological nutrient removal, activated sludge with biological nutrient removal and filtration or membrane treatment, contains nutrients at a relatively low concentration. In these cases, TWW's contribution to the fertilization programme is low to negligible.

Table 2 — Typical range of TWW quality after treatment[a]

Constituent	Unit	Raw wastewater	Primary	Conventional activated sludge	Activated sludge with biological nutrient removal	Membrane bioreactor
Ammonia nitrogen	mg N l^{-1}	12 to 45	21	1 to10	1 to 3	1 to 5
Nitrate nitrogen	mg N l^{-1}	0-trace	0,1	10 to 30	2 to 8	< 10
Total nitrogen	mg N l^{-1}	20 to 70	51,6	15 to 35	3 to 8	< 10
Total phosphorus	mg P l^{-1}	4 to 12	5,1	4 to 10	1 to 2	0,3 to 2

a Modified from Reference [6].

Compared to nitrogen and phosphorus, whose concentration varies according to the level of treatment, the potassium concentration does not change because conventional wastewater treatment does not remove salts. Therefore, the concentration will be similar to the concentration in raw wastewater.

Evaluation of the fertilizer value of the TWW should be made based on reservoir water samples, as explained in 12.1.

6 Nutrient cycle and reactions in soil

6.1 General

The part of the nutrients added with the TWW that will be available for the plants depends on the reactions of the nutrients in the soil.

6.2 Nitrogen

The nitrogen cycle in the soil is presented in Figure 1.

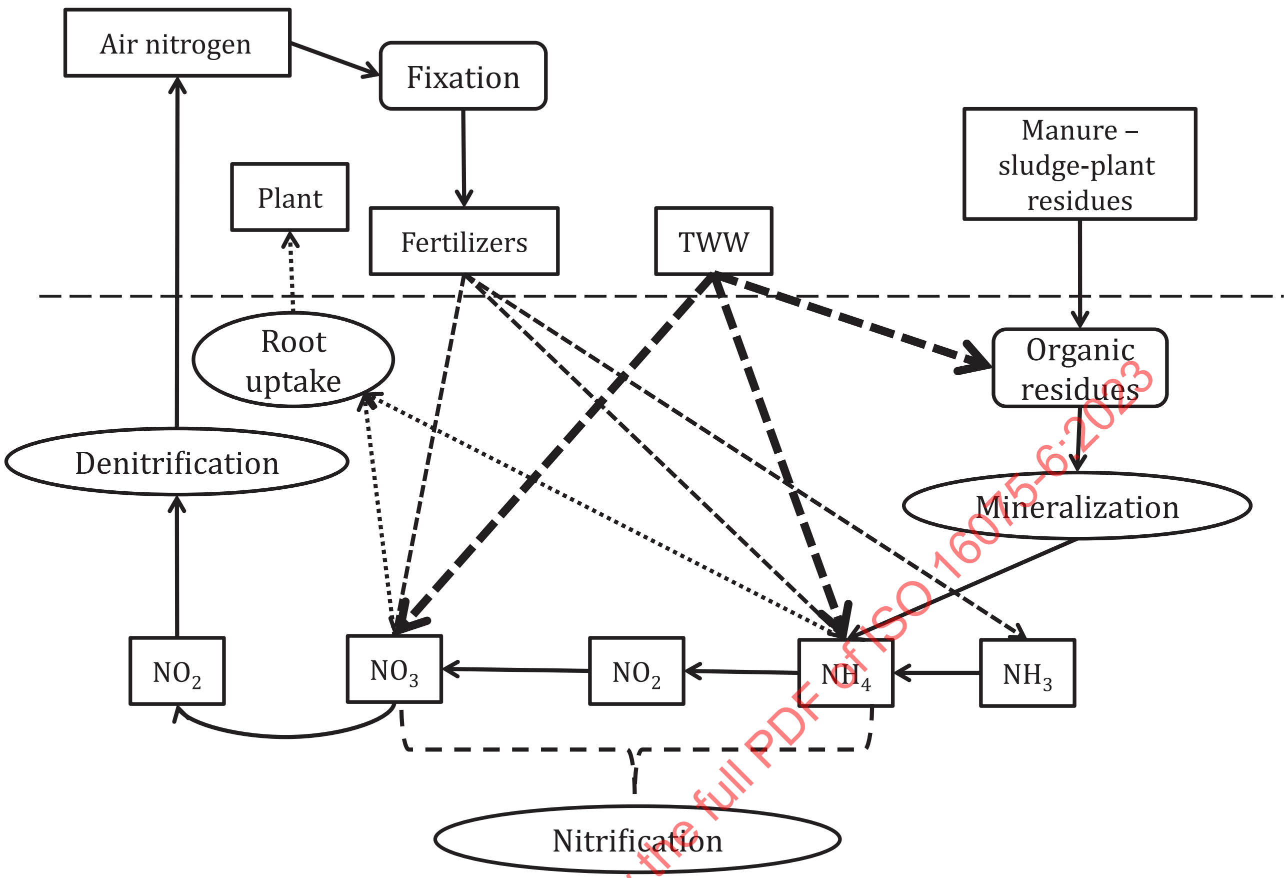


Figure 1 — Nitrogen cycle in the soil

The total nitrogen content in soil is composed of inorganic and organic compounds.

The inorganic forms of soil nitrogen include ammonium (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-) and gaseous forms (N_2O; NO; N_2). From the point of view of plant nutrition, ammonium (NH_4^+) and nitrate (NO_3^-) are of the greatest importance.

The organic forms of soil nitrogen are present as amino acids, amino sugars and other organic fractions.

Plants absorb the nitrogen in the forms of ammonium and nitrate in a proportion according to the plant's stage of development, type of plant and soil environment.

A fraction of organic soil nitrogen can be mineralized and become available in ionic forms. Nitrogen mineralization is the production of inorganic N (generally ammonium) from organic nitrogen. The percentage of organic nitrogen in TWW can vary between 10 %[7] and 30 %,[8] with higher values in TWW of lower treatment levels (see also Table 2).

Ammonium is a monovalent cation partitioned between the soil solution and the exchange complex of the clay minerals in the soil.

Nitrification is the process of oxidation of ammonium to nitrate. It is a two-step microbial process, consisting of the conversion of ammonium to nitrite and then further oxidation to nitrate in a process mediated by aerobic-autotrophic bacteria. The pathway of the nitrification process is presented in Formulae (1) and (2).

$$NH_4^+ + 1½\ O_2 \rightarrow NO_2^- + H_2O + 2H^+ \quad (1)$$

$$NO_2^- + \frac{1}{2} O_2 \rightarrow NO_3^- \quad (2)$$

The soil bacteria responsible for the first oxidation step are mainly *Nitrosomonas* spp, while *Nitrobacter* spp are involved in the second step.

Nitrate ion is not likely to be retained in most soils as a result of its negative charge and weak adsorption in the soil. Therefore, some can be lost through leaching below the rooting zone and eventually to the groundwater. Losses can also occur as gas by the denitrification process.

At the moment that TWW nitrogen reaches the soil it becomes part of the soil nitrogen cycle. The ammonium in the TWW, as well as that derived from organic matter mineralization, is nitrified to nitrate, at a rate depending on soil characteristics and environmental conditions.

6.3 Phosphorus

The phosphorus cycle in the soil is presented in Figure 2.

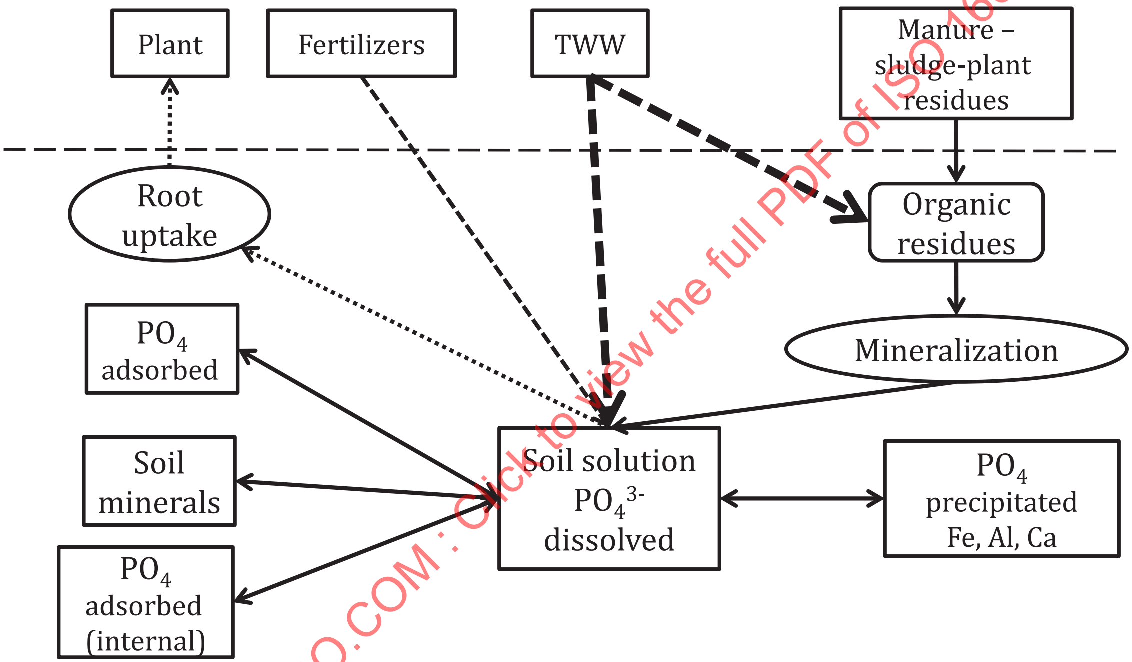


Figure 2 — Phosphorus cycle in the soil

Phosphorus is present in soil in both organic and inorganic compounds, the inorganic phosphorus fractions being higher than the organic phosphorus.

Phosphorus is absorbed by the plants as orthophosphate ions ($H_2PO_4^-$ and HPO_4^{2-}) from the soil solution. The concentration of each ion depends on soil solution pH. At pH 7,2 the two forms are in similar concentration. Below this pH, the main ion is $H_2PO_4^-$; at higher pH values the HPO_4^{2-} ion is predominant. Under alkaline conditions, the solubility of phosphorus is low, therefore P is in the form of salts of low solubility and only a small fraction is found in the soil solution.

Low soluble phosphorus compounds are formed by precipitation. At low pH they are formed with Fe^{3+} and Al^{3+}; at higher than pH 7 they are formed with Ca^{2+}. Phosphorus is also adsorbed to clay minerals in the soil by different sorption reactions. These various phosphorus forms and their reactions maintain an equilibrium with the soil solution, from which the plant absorbs phosphorus.

The phosphorus added during TWW irrigation becomes an integral part of the phosphorus cycle in the soil, contributing organic phosphorus to the pool of fresh organic phosphorus, which after decomposition of the organic matter releases phosphorus as inorganic phosphorus in the soil. The inorganic phosphorus added by the TWW is incorporated into the soil solution and reacts as described previously, either precipitated or adsorbed.

6.4 Potassium

The potassium cycle in the soil is presented in Figure 3.

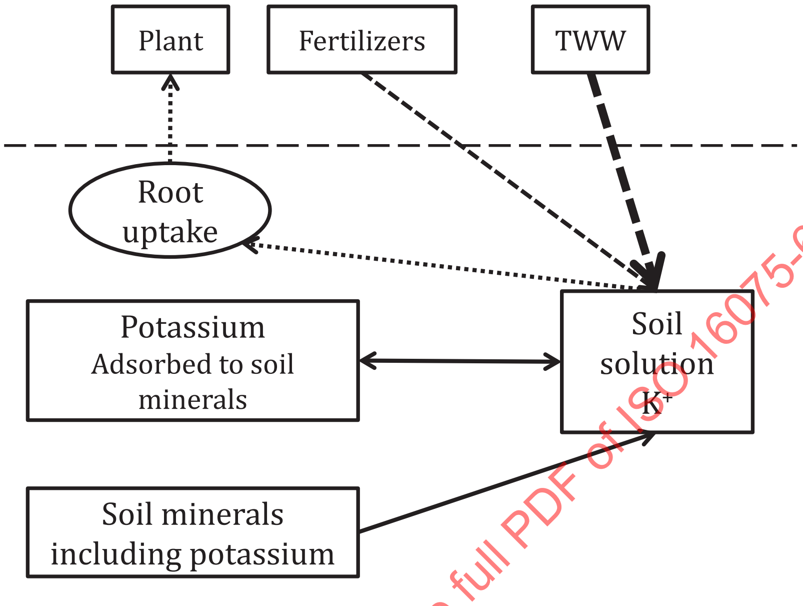


Figure 3 — Potassium cycle in the soil

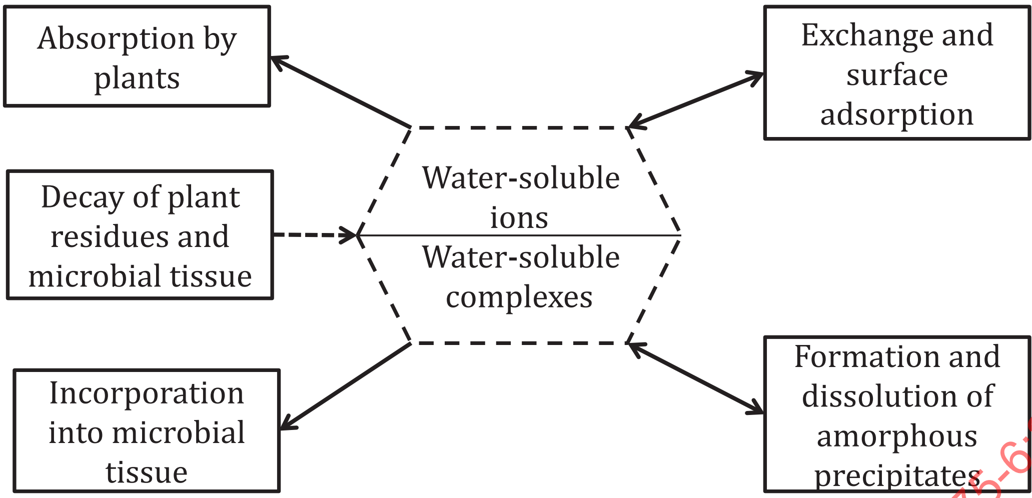
Potassium in soil can be classified into three fractions: potassium as a structural element in soil minerals, K^+ interchangeable adsorbed to soil colloids (clays and organic matter) and K^+ present in soil solution.

The proportion of K^+ in the soil solution is small relative to K^+ in the other fractions. Adsorbed potassium can be released into solution, as well as potassium in minerals by the weathering process.

The K^+ applied by irrigation with TWW is dissolved and is in the ionic form. The K^+ added in TWW irrigation becomes an integral part of the K^+ cycle in the soil, is incorporated into the soil solution and reacts as described previously, being adsorbed.

6.5 Micronutrients

The possible pathways of micronutrients in soil are presented in Figure 4.



a Modified from Reference [11].

Figure 4 — Possible pathways of trace element in soil[a]

The main mechanisms that immobilize dissolved trace elements within the soil appear to be adsorption and precipitation. Factors that affect the retention of trace elements by soils include soil texture, soil pH, soil organic matter and contents of amorphous oxides of Fe, Al and Mn.[8] The soil pH is a determinative factor for trace element solubility in soils and in the absorption (uptake) of these by the plant.

Trace elements are found in TWW both in the suspended and dissolved solids. Suspended solids can accumulate on the soil surface and the dissolved trace elements penetrate into the soil. Tillage operations tend to homogenize the elements from both fractions in the tilled soil.[8]

A benefit of using TWW for irrigation can be the addition of elements which can correct micronutrient deficiencies in high pH and calcareous soils.[7] Accumulation of excessive levels of trace elements can be a concern, as it could lead to plant toxicity and hence to health and environmental hazards. The potential negative effects of trace elements are presented in ISO 16075-1.[10]

7 Fertilizer requirements

7.1 Nutrient requirement by crops

Developing a fertilization programme starts with understanding the crop's nutrient needs in its different growth stages. Each crop requires different amount of nutrients according to the plant characteristics, the expected crop production and environmental considerations.

Some examples of nutrient demand as a function of relative time and stage of growth are presented in Table 3 for two crops.

Table 3 — Nutrient uptake for cotton and maize with respect to relative time of growth[a]

Crop	Nutrient	Uptake kg ha^{-1}					Total uptake kg ha^{-1}
		Relative time of growth %					
		0 to 20	20 to 40	40 to 60	60 to 80	80 to 100	
Cotton	Nitrogen	5	45	95	55	40	240
	Phosphorus	4	6	20	11	4	45
	Potassium	15	50	90	15	5	175
Maize	Nitrogen	15	95	150	50	30	340
	Phosphorus	1,8	7,5	7	6,3	2,5	25
	Potassium	15	110	60	20	5	210

[a] Modified from Reference [12].

Table 3 demonstrates three important properties in the uptake of nutrients by crops:

— there is a difference in the total nutrients used by different crops;

— in each crop, the amount of nutrients consumed varies with expected crop production and the state of development of the crop;

— the N:P:K relationship varies with the state of development of the crop and with the expected crop production.

Accordingly, the total amount of a nutrient to be applied is important, but the amount that should be applied at each stage as well as the relationship between the nutrients is more important.

To ensure rational fertilization, the plant should be supplied with the nutrients it needs at the right time, in the right amount and in the right form. It is important to make a nutrient balance to account for the macronutrient given to the plant by other sources besides those nutrients given by the irrigation water (e.g. nutrients given by the soil). To know the amount of macronutrient given by other sources, a soil analyses and foliar analysis can be carried out.

7.2 Soil fertility assessment

In order to prepare the fertilization plan for the plot to be irrigated, the soil should be periodically analysed, including the following determinations: forms of nitrogen, assimilable phosphorous and potassium, organic matter and pH.

In the case of trees or shrub crops which are already established, namely vines, orchards and olive groves, where foliar analysis is more suitable for assessing the nutrition of the plant, this diagnostic method may be used, together with soil analysis, as a basis for calculating crop requirements. In this case, soil analysis will be carried out less frequently, for example every 4 years.

With the results of the soil analysis and knowledge of the crop nutrient requirements, the fertilizer requirements of the crop can be established.

8 Calculation of nutrient contribution by TWW

8.1 General

Calculating the amount of nutrients provided during TWW irrigation is an essential step in developing a comprehensive fertilization plan that considers the contribution of TWW, inorganic fertilizers and organic amendments.

The amount of the nutrients applied with the TWW during a given period is calculated as the product of the applied TWW dose (water volume per unit area) multiplied by the concentration of the nutrient in the TWW (determined by an analysis of that water), as demonstrated by the examples presented in 8.2 to 8.4 for three macronutrients.

8.2 Nitrogen

The calculation of nitrogen applied follows Formula (3).

$$N_{ap} = N_{conc} \cdot W_d / 1\,000 \tag{3}$$

where

N_{ap}	is total nitrogen applied in a determined period (kg ha^{-1});
N_{conc}	is total nitrogen concentration in TWW (g m^{-3});
W_d	is TWW dose applied in a determined period (m^3 ha^{-1});
1 000	is unit conversion factor from g ha^{-1} to kg ha^{-1}.

However, not all the nitrogen in the TWW is immediately available for consumption by the crop. The organic nitrogen fraction will be available only after the mineralization process. The secondary TWW contains approximately 85 % to 90 % inorganic nitrogen. Multiplying the N_{ap} obtained in Formula (3) by a factor of 0,85 to 0,90 will provide the nitrogen available to the crop, see Formula (4).

$$N_{av} = N_{ap} \cdot F_{inorg} \tag{4}$$

where

N_{av}	is available nitrogen (kg ha^{-1});
F_{inorg}	is the factor that expresses the percentage of inorganic nitrogen in the TWW; for secondary TWW the value is 0,85 to 0,90.

As the relationship between inorganic and organic nitrogen varies with the level of treatment and can also vary according to the residence time in the reservoirs, it is preferable not to use a fixed factor but rather the sum of the concentration of ammonium-nitrogen plus nitrate-nitrogen for calculations.

8.3 Phosphorus

The calculation of phosphorus applied follows Formula (5).

$$P_{ap} = P_{conc} \cdot W_d / 1\,000 \tag{5}$$

where

P_{ap}	is total phosphorus applied in a determined period (kg ha^{-1});
P_{conc}	is total phosphorus concentration in TWW (g m^{-3});
W_d	is TWW dose applied in a determined period (m^3 ha^{-1});
1 000	is unit conversion factor from g ha^{-1} to kg ha^{-1}.

Since phosphorus content in fertilizers is expressed as pentoxide (P_2O_5), the calculated phosphorus should be multiplied by a factor of 2,2 to convert the value to pentoxide form.

8.4 Potassium

The calculation of potassium applied follows Formula (6).

$$K_{ap} = K_{conc} \cdot W_d / 1\,000 \qquad (6)$$

where

K_{ap}	is total potassium applied in a determined period (kg ha^{-1});
K_{conc}	is potassium concentration in TWW (g m^{-3});
W_d	is TWW dose applied in a determined period (m^3 ha^{-1});
1 000	is unit conversion factor from g ha^{-1} to kg ha^{-1}.

Since potassium content in fertilizers is expressed as oxide (K_2O), the calculated K should be multiplied by a factor of 1,2 to convert the value to oxide form.

9 Scheduling of nutrient supply rate by TWW according to crops’ needs

9.1 Growth season total nutrient application

The nutrient contribution of using TWW should be calculated in conjunction with the total of each nutrient that will be applied to a given crop during the irrigation season.

EXAMPLE

— Crop: cotton.

— Irrigation dose: 500 mm (5 000 m^3 ha^{-1}).

— Nutrient concentrations in TWW: total nitrogen 35 mg l^{-1} and total phosphorus 10 mg l^{-1} (conventional activated sludge treatment, see Table 2) and potassium 20 mg l^{-1}.

$$N_{ap} = 35 \text{ g m}^{-3} \cdot 5\,000 \text{ m}^3 / 1\,000 = 175 \text{ kg N ha}^{-1}$$

$$N_{av} = 175 \text{ kg N ha}^{-1} \cdot 0{,}9 = 157{,}5 \text{ kg N ha}^{-1}$$

$$P_{ap} = 10 \text{ g m}^{-1} \cdot 5\,000 \text{ m}^3 / 1\,000 = 50 \text{ kg P ha}^{-1}$$

$$P_2O_5 = 50 \text{ kg P ha}^{-1} \cdot 2{,}2 = 110 \text{ kg } P_2O_5 \text{ ha}^{-1}$$

$$K_{ap} = 20 \text{ g m}^{-3} \cdot 5\,000 \text{ m}^3 / 1\,000 = 100 \text{ kg K ha}^{-1}$$

$$K_2O = 100 \text{ kg K ha}^{-1} \cdot 1{,}2 = 120 \text{ kg } K_2O \text{ ha}^{-1}$$

Using this example, if the amounts of nutrients applied are compared with the total uptake by the crop (Table 3), less nitrogen and potassium were applied than necessary, but there is a certain phosphorus excess, without taking into account nutrients present in the soil from previous crops.

9.2 The distribution of nutrient application throughout the irrigation season

The application depends on the concentration of the nutrients in the TWW and the amount applied in each period of crop growth. An example is presented in Table 4, which uses the same data and formulae used in 8.1 and the irrigation dose for each period.

The last row presents the difference between the recommended nitrogen fertilization and the N applied with the irrigation water. Positive numbers express an excess of nitrogen applied with the TWW. Negative numbers represent that the amount of nitrogen applied with the water does not cover the needs of the crop.

Table 4 — Comparison between monthly nitrogen fertilization programme and N applied with TWW

Growth week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Irrigation (m^3 ha^{-1})	—	140	300	300	330	360	510	550	550	510	410	370	300	250	120
Nitrogen fertilizer recommended (kg ha^{-1})	—	—	40	16	16	22	28	28	28	—	—	—	—	—	—
Nitrogen applied with TWW (kg ha^{-1})	—	4,4	9,5	9,5	10,4	11,4	16,1	17,3	17,3	16,1	12,9	11,7	9,5	7,9	3,8
Difference (kg ha^{-1})	—	4,4	−30,5	−6,5	−5,6	−10,6	−11,9	−10,7	−10,7	16,1	12,9	11,7	9,5	7,9	3,8

These shortages and excesses are unavoidable for two main reasons:

— the amount of water applied is based on the water needs of the crops and not programmed to satisfy the nutrient requirement;

— the concentration of nutrients in the TWW of a given source is relatively constant, meaning that it cannot be increased in periods of higher consumption or removed completely in times of excess.

Excess nitrogen and phosphorus can be higher than the values presented in Table 4 as the soil could already contain nitrogen from mineralization and/or from residues of previous crops, while the excess of phosphorus can occur from previous fertilizations.

During periods of shortage, inorganic fertilizer may be added to satisfy the plant's needs.

In cases of excess, there is no possible solution other than treating the wastewater to a level that removes the nutrients (nitrogen and phosphorus), which can represent an additional cost for final TWW users. In the case of nitrogen, this will be possible by a nitrification or denitrification treatment process that reduces its concentration in the TWW. Phosphorous can be reduced by chemical precipitation. The removal of potassium can be made with advanced treatments such as reverse osmosis.

These excesses can affect crops and the environment. An excess of nitrogen can delay the ripening of fruit on trees or the development of fruit colour. It can also decrease the shelf life of fruit kept in refrigeration by the grower or consumer.

Excess nitrogen in the soil can be leached into groundwater sources.

This calculation does not take into account two aspects that can reduce the need to apply fertilizers at the beginning of the irrigation season: if a technical irrigation is carried out in field crops for the purposes of germination or to increase the amount of water in the soil profile, this will also be done with TWW, so nitrogen will be added pre-season of irrigation.

Residual nitrogen in the soil, resulting from the application of nitrogen with TWW, fertilizers and fertilizers in the previous season and from crop residues of previous crops, should also be taken into account.

Phosphorus, which is very commonly over-applied in TWW irrigation, accumulates in high concentrations in the upper soil layer and can leach or runoff into ground or surface waters.

Similarly, but to a lesser extent, accumulation of potassium in the soil can develop in crops with low potassium consumption or with TWW with high potassium concentration (such as TWW that originate in dairy farms). High soil concentration of these nutrients can be antagonistic to the uptake of micronutrients by the crops. If a micronutrient deficiency is suspected for this reason, the application of a fertilizer containing micronutrients may be considered.

10 Adjusting fertilizers for use with TWW

If it is necessary to add fertilizers to the TWW, the type of fertilizer should be adapted to the characteristics of the irrigation water.

A large range of fertilizers, solid and liquid, are suitable for fertigation (fertilization through irrigation) depending on the physicochemical properties of the fertilizer and the water quality.[12]

High and complete solubility is a prerequisite for fertilizers incorporated in the irrigation water. The solubility of a fertilizer is defined as the maximal amount of the fertilizer that can be completely dissolved in a given amount of water at a given temperature.

The fertilizer solubility generally increases with the temperature and depends on the water pH.

However, in addition to considering the intrinsic characteristics of solubility of the fertilizer, the compatibility of fertilizer compounds with the characteristics of the irrigation water should also be taken into account. For example, some water types can contain relatively high concentrations of divalent cations, such as calcium and magnesium.

A special case is TWW, whose chemical composition depends on the water supplied to consumers and the pick-up of salts during use (domestic, industrial and agricultural). An example of range of increment of inorganic constituents is presented in Table 5.

Table 5 — Inorganic constituents added to wastewater through domestic water use[a]

Constituent	Range of increment mg l^{-1}
Total dissolved solids	150 to 380
Sodium	40 to 70
Potassium	7 to 25
Calcium	6 to 16
Magnesium	4 to 10
Chloride	20 to 60
Carbonate	0 to10
Bicarbonate	50 to100
Sulfate	15 to 30
Alkalinity (as calcium carbonate)	100 to 150
Boron	0,1 to 0,4
Phosphate	5 to 15
Ammonium	15 to 40

[a] Modified from References [6] and [8].

Generally, the chemical composition of TWW is significantly different from the potable water provided in the area, which can be important if its interaction with the fertilizer produces insoluble products that precipitate in the irrigation system, causing clogging.

Examples of such reactions include the following:[13]

— Calcium: injecting a fertilizer that contains calcium (e.g. calcium nitrate) into irrigation water that has more than 2 meq l^{-1} bicarbonate and a pH greater than 7,5 can cause calcium carbonate to precipitate.

— Sulfate: injecting a fertilizer that contains sulfate into irrigation water that has a calcium concentration of more than 2 to 3 meq l^{-1} can cause calcium sulfate (known as gypsum) to precipitate.

— Phosphorus: injecting a fertilizer that contains phosphorus can cause a reaction with calcium and magnesium in the irrigation water, causing phosphate precipitates when calcium or magnesium concentrations are higher than 2,5 meq l^{-1} or 40 mg to 50 mg l^{-1}, respectively. These precipitates can be difficult to dissolve and remove from emitters.

The compatibility of new fertilizers with irrigation water should be checked regularly because the quality of TWW is highly variable between different zones and over time in a reservoir, even within the irrigation season.

To check solubility and potential precipitation with the local TWW, 10 ml to 20 ml of the fertilizer solution can be mixed with 1 l of the irrigation water and observed for precipitation for up to 2 h. If precipitates are formed or the sample becomes cloudy, this fertilizer is incompatible with the irrigation system.[12]

11 Combining organic amendments and fertilizers in plots irrigated with TWW

Organic amendments containing nutrients (Table 6) may be applied as part of the fertilization programme. However, when fertilizing TWW irrigated plots, priority is given to the nutrients applied with the water. Only when TWW concentrations are low can nutrient needs be met with inorganic fertilizers and/or organic amendments. This case is only for TWW in which the nutrients have been removed during the treatment.

Table 6 — Examples of nutrient content in organic amendments from agricultural and municipal sources[a]

Organic residue source	Treatment	Organic matter content	N	P	K
		%			
Dairy cattle	Anaerobic digestion	72,7	1,8	1,2	1,9
	Composting	21,8	1,1	1,1	1,4
Poultry	Composting	80,0	4,8	1,2	2,2
Wastewater sludge (biosolids)	Composting	43,1	2,3	1,6	0,4
Municipal solid waste	Composting	34,0	0,8	0,3	0,5

[a] Modified from Reference [14].

12 Monitoring in the context of nutrient value of TWW

12.1 Water monitoring

12.1.1 Sampling

12.1.1.1 General

Sampling of TWW should be done by a skilled employee as follows:

The sample can be grabbed from the outlet of the WWTP or reservoir, as long as homogenization in the plant and the reservoir produces a stable TWW quality.

All samples should be well labelled, indicating the type of water, site location, date, time and other pertinent data.

Sampling frequency should be defined according to the TWW quality variation expected over the irrigation season, to obtain representative data of the nutrient concentration that will be used in the fertigation programme.

12.1.1.2 Sampling from an irrigation system

Water sampling should be taken prior to fertigation, not while it is taking place.

Water quality should be checked by the end user as follows:

— turn on the irrigation system until the system operates at full designed pressure and let the system irrigate until the pipes have flushed of all stagnant water from the previous irrigation event;

— collect a sample from a tap located at the entrance to the irrigation system or from an irrigation emitter (a sprinkler, micro-jet or dripper);

— collect the water sample in bottles (1 l HDPE or PP bottles with double caps or self-sealing caps, with or without air) as provided or recommended by the analytical laboratory or procedure and the parameters to be tested;

— write all necessary details on a sticker attached to the bottle (e.g. name, address, date, location) and seal the lid;

— preserve samples according to standard laboratory practice, without any additives for potassium and with H_2SO_4 (to pH = 2) for nitrogen and phosphorus;

— transport the samples to an analytical laboratory, within the time period recommended for the analysis, in a dark refrigerated container at 4 °C.

Sample preservation and transport measures are not relevant when analysed in the field.

For more information about sampling from an irrigation system, see ISO 5667-10.[16]

12.1.1.3 Sampling from a storage reservoir

To evaluate the variability of TWW quality during storage, to evaluate the fertilization value, a sample from the storage reservoir should be taken at the exit of the reservoir's pumping station.

The water sampling should be done as close as possible to the beginning of the irrigation period of the crop, in order to know the amount of nutrients present and make the nutrients balance.

In periods of no irrigation from the reservoir, the sample should be taken directly from the storage reservoir, as follows:

— take the sample as close as possible to the pumping point;

— avoid sampling downwind to prevent the collection of floating materials (plant or algae residues) transported by water waves to the downwind side of the storage reservoir;

— attach an empty bottle to the sampling pole;

— lower the bottle so that the neck is submerged in the storage reservoir to a depth of about 10 cm and fill the bottle;

— remove the bottle from the storage reservoir, seal it and label the bottle;

— preserve samples according to standard laboratory practice, without additives for potassium and with H_2SO_4 (to pH = 2) for nitrogen and phosphorus;

— transport the samples to an analytical laboratory, within the time period recommended for the analysis, in a dark refrigerated container at 4 °C.

For more information about sampling from a storage reservoir, see ISO 5667-4.[17]

12.1.2 Analysis

12.1.2.1 Field test

In sites where laboratories are far, field analysis, when available, is a feasible way to obtain certain water quality information.

The field test results can be less accurate than those obtained in a well-equipped laboratory due to the lower reproducibility of measuring devices used for field tests.

Either way, the accuracy of the field determinations is sufficient for the TWW's quality control needs during the irrigation season, especially when TWW is periodically characterized in a laboratory.

For the purposes of monitoring the fertilization programme, the concentrations of the forms of nitrogen, phosphorus, potassium and pH should be measured.

The analysis methods may be using colorimetric methods that have as a reference a specific colour table for the determined parameter or small portable photometers. These photometers may be specific for the determination of a parameter and therefore work only in the wavelength of the colour that will be developed for that parameter or those that can change the wavelength and can serve for all determined parameters.

12.1.2.2 Laboratory testing

Monitoring frequency should be adjusted to local conditions, for example irrigated crops, climate, soil and irrigation technique. At the beginning of a new project, monitoring frequently will help identify the parameters with high variability. Determining a monitoring schedule should depend on fluctuations in a parameter's concentration, with stable parameters requiring less frequent monitoring.

Table 7 presents the parameters to be analysed for the fertilization programming and adaptation of fertilizers to the water quality.

Table 7 — Monitored parameters for fertilization using TWW for irrigation

Monitored parameters	Units
Nutrients Total Kjeldhal nitrogen Ammonia nitrogen Nitrites Nitrate-nitrogen Total nitrogen Total phosphorus Potassium	mg l^{-1}
Major solutes Na, Ca, Mg, K, Cl, SO_4, HCO_3, CO_3	mg l^{-1}

Using standard methods in a laboratory with a quality control programme provides reliable information.

12.2 Soil

12.2.1 Soil sampling

Irrigating with TWW can lead to greater nutrient accumulation in the root zone and affect the plants. In order to optimize the fertilization management optimally, soil should be monitored.

