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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
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Foreword

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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].

NOTE This document is not intended to be used for certification purposes.

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}	4–12	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.

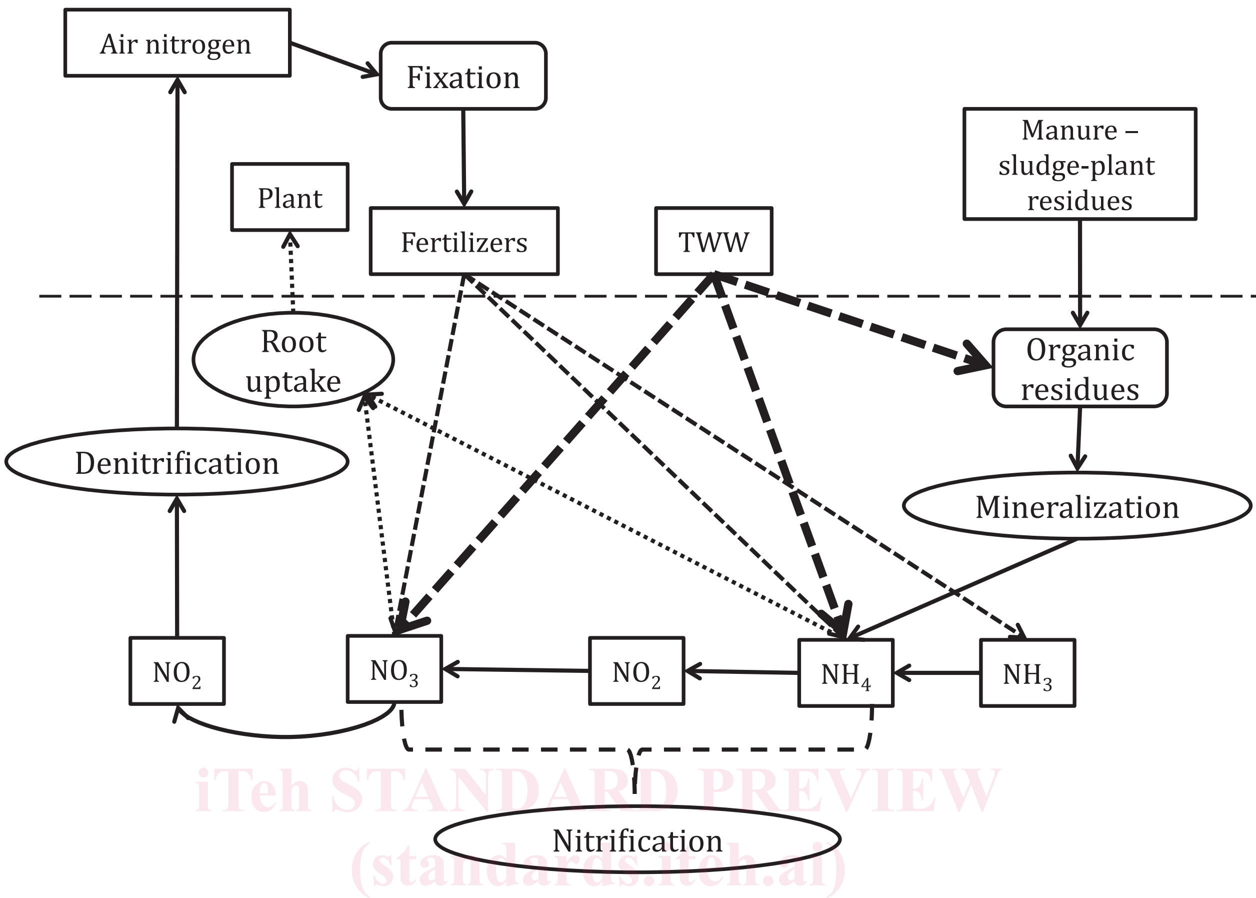

Figure 1 — Nitrogen cycle in the soil

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).

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

