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WATERQUALITY CRITERIA
FOR AGRICULTURAL WATER USE

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INTRODUCTION

Since this document is concerned with waterquality criteria for agricultural purposes the crop is perhaps the most important factor to be considered. The evaluation of a water must be based on the tolerance of a specific crop or crops in relation to the soluble salt content or specific ion concentration. Plants vary considerably in their tolerance to water quality constituents. In addition to differences between species and varieties, there are often also differences in tolerance according to the stage of growth.

A large amount of information is available relating crop tolerances to salinity, but very little is known on tolerances to trace elements that may be present in the water.

Irrigation is necessary in the Netherlands for intensive crop production in greenhouse horticulture and is used to supplement rainfall in agriculture in the open. The effects of water quality characteristics on soil and on plant growth are related to the frequency and the amount of irrigation water added. The two main climatic factors having greatest influence on irrigation water needs are evapotranspiration and rainfall.

The rate of evapotranspiration affects not only the irrigation need, but also the reaction of the plant to a given soil condition. A plant will generally suffer more in a saline soil at a given water content under conditions of a high evapotranspiration rate, than under a low rate.

Rainfall is a significant factor, because it increases the amount of available water in the soil, diluting the soil solution and under conditions of a precipitation surplus leaching of the soil is present.

The water quality criteria for irrigation water, in particular for specific ion effects are generally based on experimental data with solution cultures and sand beds. So these data refer only to the short term effects and they have no significance for long term effects due to accumulation in the soil. The levels proposed, taking into account these accumulation effects, have been obtained by extrapolation in most cases. The validity of the extrapolation procedure might be subject to further discussion. Moreover, the levels have been based on a yearly irrigation of 500 mm.
No attempt has been made to consider combined effects due to the presence of more than one element in the irrigation water.

SALT ACCUMULATION IN SOILS DURING GROWTH

The effect of levels of salt in irrigation water on plant growth is determined by the composition of the equilibrium soil solution. This is the growth medium available to the plant roots after soil and water have reacted.

Evapotranspiration removes pure water from the soil leaving salts behind. Since salt uptake by plants is negligible, salts accumulate in the soil. A more or less favourable salt balance in the rootzone can be maintained by leaching using irrigation water in excess of plant needs. There is no definite relationship between the concentration and composition of the irrigation water and that of the soil solution. The latter concentration may in some cases be several times greater than that of the irrigation water.

Practical experience in the Netherlands shows that the mean concentration of the soil solution in green houses is 1.7 to 2.2 times that of the irrigation water for clay and sandy soils respectively.
In the open the concentration depends strongly on the amount of precipitation during growth. With normal amounts of precipitation during growth the mean concentration of the soil solution is about 0.5 to 1.0 times that of the irrigation water, while in dry summers these figures can be 1.0 to 2.0. These data have been used to relate the concentration in the irrigation water to crop reaction.

SALINITY

The salinity or total soluble salt concentration of an irrigation water is an extremely important water quality consideration. An increase in water salinity causes an increase in osmotic pressure of the soil solution resulting in a reduced availability of this water for the plant. Consequently plant growth may be severly retarded. This osmotic effect is generally related to the total concentration of dissolved salts rather than to the individual concentrations of specific ionic constituents.

Though it is well known that chloride has also toxic effects on a number of plant species, no difference will be made between the effect of total soluble salt concentration and chloride concentration. A close relation exists in the polder water of the Netherlands between total salt concentration and chloride concentration(VAN DEN BERG, 1962).

Plants vary in their tolerance to soil salinity. The recommendation of a single set of criteria for irrigation water is impossible because of the large variation in salt sensitivity. Many crops show progressive decrease in growth rate and size with increasing salinity of the applied irrigation water.

Many of the data on plant tolerance to salinity have been obtained from artificial field plots, that were managed, by means of high leaching fractions to obtain nearly uniform salt distribution throughout the rootzone. Experience of several years confirms that such data are reproducible and reliable.

It is impossible to give a single value of the allowed salt concentration in irrigation water, due to the great variability in salt tolerances of the crops, as well as the variation in culture practices. For the main crops in greenhouse horticulture yield reductions start when the irrigation water has a salt concentration of 800, 400 and 160 mg/l for tomato, pepper and cucumber respectively. These data correspond with a chloride concentration of 200, 100 and 40 mg/l. With each additional increase of the salt concentration with 400 mg/l (100 mg Cl^-/l) the yield reduces with 4, 4 and 7 % respectively for tomato, pepper and cucumber(BIERHUIZEN en PLOEGMAN, 1967; PLOEGMAN, 1969; PLOEGMAN en BIERHUIZEN, 1970; SONNEVELD en VAN DER ENDE, 1969, 1971).

Yield reductions of 25% of beans, beets and turnips have been observed by 0.1 mg/l in nutrient solutions, whereas cabbage and barley gave yield decreases of 20 to 50% at 1.0 mg/l.

The cadmium content of plants grown in soils containing 0.11 to 0.56 mg/kg soil acid extraxtable cadmium is 1 to 4 mg/kg dry matter. Plants showing toxic symptoms had several hunderd mg/kg. Because of the phytotoxicity of cadmium, its ability to accumulate in plants and soils, and its toxicity to man and livestock a concentration value of 0.01 mg/l is recommended as highest level.

Chromium

Chromium is present in trace amounts in soils and plants, but there is no evidence that this element is essential or beneficial for plant nutrition. In recent work it has been found that chromium concentrations as low as 0.5 mg/l in water cultures or 10 mg/kg in soil cultures significantly reduced yields. The evidence on the toxicity of chromium suggests a derived working level of 1.0 mg/l in irrigation waters, with the restriction of a recommended level of hexavalent chromium of 0.1 mg/l.

Cobalt

Cobalt toxicities have been observed for several species in sand cultures. Field occurence of cobalt toxicity is rare and strong interaction between cobalt and most soils is present at neutral and alkaline pH values. For this reason a derived maximum working level of 0.2 mg/l is suggested.

Copper

Small quantities of copper are known to be essential to plant growth. However, copper concentrations of 0.1 to 1.0 mg/l in nutrient solutions have been found to be toxic to a large number of plants.

Copper combines strongly with most soils. Consideration of possible soil accumulation of copper and toxicity levels in nutrient solutions suggest a derived level for copper in irrigation water of 0.2 mg/l for continuous use on all soils.

Generally, copper toxicities in animals would be expected to be feed-related rather than water-related. Chronic poisening of sheep has been caused by 1.5 gram of copper sulfate daily for 30 to 80 days. Around 9 mg of copper per day has been stated as a safe intake level for sheep. Effects of copper toxicity are aggrevated by molybdenum deficiancies. Depending on the dietary intake of copper, the derived level of copper for livestock drinking water will range from 0.05 - 0.2 mg/l.

Iron

Iron in irrigation water can cause a variety of problems including damage to plants, clogging of irrigation equipment and corrosion of iron pipes and tanks. On plants iron may produce light brown spotting. Problems will become apparent when the total iron concentrations are around 2.0 mg/l.

Lead

Compared with other trace elements, the phytotoxicity of lead is relatively low. Toxicity has been reported in nutrient solutions containing lead around 1 mg/l. Lead is absorbed strongly by soils and it is to be expected that soluble lead in irrigation water will be taken up by the soil and rendered unavailable for crops. Recent work has shown that the entry of lead into plants is from aerial deposits rather than from absorption from soils.

Because of the relatively low toxicity of lead to plants and the high capacity of soils to inactivate it, allows the recommended level for lead in irrigation water to be set at 1.0 mg/l.

Lead contamination of livestock drinking water supplies may be caused by dissolved lead salts or by insoluble lead salts in suspension. Lead is especiably dangerous because it is a cumulative poison.

However, there seems to be fairly general agreement in literature that a level of 0.5 mg/l for lead in the drinking water of livestock should provide an adequate safety margin.

Manganese

Manganese is essential for plant growth, apparently as an enzyme activator. It is especially abundant in the reproductive points of plants, being highest in seeds.
Manganese toxicities have been observed down 0.5 mg/l but large variations occur, depending upon plant species and possible nutrient imbalances. Toxicities due to manganese are usually associated with acid soils.
Considering the available data a maximum level of 0.5 mg/l is recommended.

Mercury

It is necessary to consider levels of mercury in livestock drinking water because mercury levels may accumulate in certain tissue and present a health hazard to humans consuming meat. It has been suggested that maintanance of mercury levels in livestock blood and tissue not exceeding 0.1 mg/l and 0.5 mg/kg respectively should provide a safe level for human consumption. It is necessary from the viewpoint of human health that mercury levels in foods are extremely low considering the other mercury sources present in the environment (mainly airborn). For this reason the derived maximum level for livestock drinking water is to be set at 0.002 mg/l.

Molybdenum

Molybdenum in very low concentrations has been found to be essential for healthy growth of plants. The accumulation of molybdenum in plants is almost proportional to the amount of the element added to the soil. In nutrient and soil solution experiments 0.01 mg/l of molybdenum in solution will produce legumes containing around 5 mg/kg in the tissue. The principal detrimental effect of molybdenum is the toxicity of these plants to cattle eating them. Effects of molybdenum toxicity are aggravated by conditions of copper deficiency and high sulfur intake. Toxic levels for molybdenum in forage crops are generally considered to be above 5 to 6 mg/kg for cattle and 10 to 11 mg/kg for sheep.

On the basis of possible animal toxicity from forage crops the maximum concentration in irrigation water is to be set at 0.01 mg/l.

Nickel

Data of sand and solution culture experiments show that nickel at concentrations from 0.5 to 1.0 mg/l is toxic to a number of plants. Considerations of possible soil accumulation of nickel from irrigation water and the toxicity in nutrient solutions give as derived level for nickel in irrigation water 0.2 mg/l

Nitrate

High nitrate concentrations in drinking water can be harmful to livestock. The nitrates are converted to nitrite by bacteria in the digestive system and than absorbed into the blood were they convert haemoglobin to methaemoglobin, thus decreasing the oxygencarrying capacity of the blood.

There seems to be a lack of evidence on which to base a limit in livestock drinking supplies. Sheep and cattle can apparently tolerate at least 200 mg/l.

It is recommended that the maximum level of nitrates in stock drinking water is set to be at 200 mg/l (as NO_3). For nitrite alone the maximum level is set at 5 mg/l

Selenium

Derived levels for selenium in irrigation water are based on animal toxicities rather than those of plants. Plants can absorb relatively large amounts of selenium without apparent injury to themselves. Selenium levels of 0.03 to 0.10 mg/kg are needed in forages to prevent selenium deficiences in cattle, but concentrations above 3 to 4 mg/kg are considered toxic. Solution culture experiments have shown that this level of selenium could result in many plant species from a concentration of 0.05 mg/l.

In view of the low levels of selenium required to produce toxic levels in forage, it is allowed to set the maximum level for selenium in irrigation water at 0.02 mg/l.

Zinc

Zinc is needed for nutrition by most crops. However, the amount must be very small since zinc concentrations of 0.3 to 1.0 mg/l have produced toxic symtons in various plants grown in standard nutrient solutions.

Considering the toxicity in nutrient solutions and possible soil accumulation of zinc from irrigation water give as derived level for zinc in irrigation water 0.2 mg/l.

PESTICIDES

The term pesticide has been used to cover all compounds used as insecticides, herbicides, etc.

Most species of aquatic life and wild life are sensitive to levels of pesticide that have little or no effect on crops. Thus the major concern about pesticides in irrigation water is the possible adverse effect on aquatic life and wild life subsequently using the water.

Pesticides vary in their persistence in the environment. The chlorinated hydrocarbons are the most persistant. One year after application the following percentages of chlorinated hydrocarbons were found to remain in the soil: DDT 80%, Dieldrin 60 to 85%; lindane 40 to 55%, chlordane 85 to 90%, heptachlor 20 to 30% and aldrin 2 to 15%. Organic phosphate and carbomate pesticides are known to be more readily hydrolysed and are less persistant. The phenoxy acid herbicides 2,4-D and 2,4,5-T are known to be subject to rapid degradation in soils.

There is little evidence that under normal use insecticide contamination of irrigation water would be detrimental to plant growth or accumulate in or on plants in toxic concentrations. Herbicides on the other hand, could be harmful to crop growth if misused. Since many herbicides decompose in water, permissable limits should be established for the point of application to crops. Some information on concentrations of herbicides in irrigation water at which crop injury has been observed is given in table 2.

Table 2. Levels of herbicides in irrigation water at which crop injury has been observed (furrow irrigation)

Herbicide	Crop injury threshold in irrigation water (mg/l)
Acrolein	Flood or furrow: beans 60, corn 60, cotton 80 soy beans 20, sugerbeets 60 Sprinkler: corn 60, soy beans 15, sugerbeets 15
Aromatic solvents (xylene)	Lucerne 1600, beans 1200, carrots 1600, corn 3000, oats 2400, potatoes 1300, wheat 1200
Copper sulphate	Apparently above concentrations used for weed control
Dalapon	Beets > 7.0 corn < 0,35
Endothall Na+k salts	Corn 25, field beans <1.0, lucerne >10.0
Dimethylamines	Corn >25, sugerbeets 25
2.4 D	Field beans 3.5 to 10, sugerbeets 3.5

Since most waters used for irrigation are also used for other purposes, the pesticide criteria for other water uses will adequately protect agricultural irrigation water.

The widespread environmental use of pesticides makes the contamination of livestock drinking water supplies possible. Table 3 contains recommended derived working levels for the three major groups of pesticides: the chlorinated hydrocarbons, the organo-phosphates and carbamates and the chlorophenoxy herbicides. These data were derived from information concerning the toxicity of there compounds to experimental animals.

Table 3. Criteria for pesticides in livestock drinking water

Pesticide	Recommended derived working level (mg/l)	Remarks
chlornated hydrocarbons		These pesticides are persistent and lopophilic
Aldrin	0.001	
Chlordane	0.003	
DDT	0.05	
Dieldrin	0.001	
Endrin	0.0005	
Heptachlor	0.0001	
Heptachlor Epoxide	0.0001	
Lindane	0.005	
Methoxychlor	1.0	
Toxaphene	0.005	
Organophosphates and carbamates	0.1	Total concentration of organophosphates and carbamates producing inhibition of acetylcholinsterase no greater than inhibition produced by 0.1 mg of parathion per litre
Chlorophenoxy herbicides		mainly used as weedkillers
2.4 - D	0.02	
2,4,5 - T	0.02	

RADIO ACTIVE SUBSTANCES

The effects of exposure of humans to excessive radiation are well recognised as being extremely harmful to health. Thus it is necessary to have strict control over the amount of radioactive material which may be ingested by man.

Vegetation, in general, is not affected by radiation levels that are considered safe for animal life. However, plants can concentrate radionuclides and there by raise the potential hazard to humans and animals consuming such vegetation. Contamination of plants to levels harmful to humans would be reached long before the plants themselves would be damaged.

Plants can absorb radionuclides from irrigation water in two ways: direct contamination of foli age through sprinkler irrigation and indirectly through soil contamination.

Important radionuclides that are absorbed and possibly concentrated by plants are strontium, caesium, barium, iodine, calcium potassium, ruthenium, zirconium, zinc and chromium.

Relatively abudant radionuclides with long half-lives such as ^{90}Sr and ^{137}Cs, may be highly concentrated in the surface layers of soil and may initiate a sequence of increasing concentrations in the plant-animal-food chain.

Decontamination of the soil is difficult because the cations are strongly absorbed and are not readily leached. Since soils accumulate radionuclides of successive irrigations the content of these substances in irrigation water should be carefully considered.

Calculations based on the maximum concentrations in the U.S. Drinking Water Standards for radionuclides ($<$ 3 pCi/l of Radium-226 and $<$ 10 pCi/l Strontium 90) indicate that water can be used continuously for irrigation around 40 and 9 years respectively for Radium-226 and Strontium-90 before detrimental effects would be noted.

It is therefore recommended that the level of radio-active substances artificially introduced into the surface water should be as low as readily achievable both for irrigation water and for livestock drinking water.

MICRO-ORGANISMS

Many micro-organisms, that are pathogenic to animals may be carried in irrigation water. Recent studies have emphasized the value of faecal coliform density as an indicator of the occurence of animal pathogens in irrigation water. It is recommended that irrigation water used for crops to be consumed raw by man or livestock should not exceed a value of 10 faecal coliform organisms/ml. Insufficient information is available to allow the formulation of levels for plant pathogens in irrigation water.

For livestock drinking water supplies the bacteriological criteria given in table 4 are to be set with regard to the faecal coliform level.

Table 4. Bacteriological criteria of water quality for livestock drinking water (Faecal coliform bacteria)

	Number of colonies/ml suitable	less suitable	unsuitable
undiluted inoculum	absent	present	
diluted 1 : 10	absent	absent	present
proteolytic colonies 1:100	<10	10 - 100	$>$ 100
colonies on agar 1 : 100	<10	1000	$>$ 1000*
colonies on gelatin 1 : 100	<10	1000	$>$ 1000

* incubated at 22° and 37°

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