agronomy

MDPI

Article

A Tool for the Evaluation of Irrigation Water Quality in the Arid and Semi-Arid Regions

Lucia Bortolini [1], Carmelo Maucieri [2,*] and Maurizio Borin [2]

[1] Department of Land, Environment, Agriculture and Forestry (TESAF), University of Padova, Viale dell'Università 16, 35020 Legnaro, Italy; lucia.bortolini@unipd.it
[2] Department of Agronomy, Food, Natural Resources, Animals and Environment (DAFNAE), University of Padova, Viale dell'Università, 16, 35020 Legnaro, Italy; maurizio.borin@unipd.it
* Correspondence: carmelo.maucieri@unipd.it; Tel.: +39-049-827-2859

Received: 19 December 2017; Accepted: 19 February 2018; Published: 22 February 2018

Abstract: In the Mediterranean arid and semi-arid regions, large amounts of low quality waters could be used for crop irrigation, but the adoption of articulated classifications with too rigid quality limits can often reduce the recoverable quantities of water and make the monitoring of water quality too much expensive. Therefore, an evaluation of irrigation water quality based on only a few crucial parameters, which consider the crop species to be irrigated and the type of irrigation system and management adopted, can be an easy and flexible method for maximizing the reuse of wastewater and low-quality water for agricultural purposes. In this view, an irrigation water quality tool (IWQT) was developed to support farmers of arid and semi-arid regions on evaluating the use of low quality water for crop irrigation. The most significant and cheapest parameters of irrigation water quality were identified and clustered in three quality classes according to their effects on crop yield and soil fertility (agronomic quality indicators), human health (hygiene and health quality indicators), and irrigation systems (management quality indicators). According to IWQT parameters, a tool reporting a series of recommendations, including water treatment types, was implemented to guide farmers on the use of low quality irrigation water.

Keywords: wastewater; brackish water; sanitary risk; contaminants; clogging

1. Introduction

In the Mediterranean region, the urban population is expected to increase [1], leading to more water consumption. Furthermore, in dry-hot areas, the availability of good quality water is very limited by low precipitation and high evapotranspiration [2] and is exacerbated under current global climate change, with extreme weather events accompanied by long dry periods [3–5]. The increasing of the population needs more and more food, but at the same time, the consequences of global climate change are compromising crops production [6]. In order to achieve satisfactory and steady crop yields, irrigation can be crucial. The agriculture sector is the largest consumer of water, especially in the Mediterranean arid and semi-arid regions, where irrigation water represents from 50% up to almost 90% of total used water [7,8]. Many Mediterranean countries—including Egypt, Libya, Tunisia, Algeria, Morocco, Syria, Malta, and Lebanon—exhibit water availability below the threshold of 1000 m^3 $person^{-1}$ $year^{-1}$ [9]. Irrigation systems with advanced technologies along with good practices can increase irrigation efficiency and reduce the water wastage [10–12]. Fader et al. [13] state that, at present, the Mediterranean region could save up to 35% of water used by implementing more efficient irrigation and conveyance systems, but it is difficult to meet the agriculture water demand only using conventional water resources. In this case, the use of wastewater or low-quality water may represent a valid solution [14,15].

Huge amounts of low-quality water, such as that coming from urban and industrial wastewater treatment plants, could be recovered and re-used for irrigation, attenuating the demand of high-quality water. At the same time, their use in irrigation may result in various problems such as toxicity for crops, damage to soil quality, diffusion of parasites, and drawbacks in irrigation systems [16–20].

Theoretically, the possibility to use low-quality water for irrigation depends on its intrinsic characteristics and on use conditions, e.g., crop type, soil and climate conditions, and irrigation method. Several variables may be considered to evaluate the quality of water and its usability for irrigation purpose. Among the different water quality classifications mentioned by the scientific literature, the most used is the FAO (Food and Agriculture Organization of the United Nations) classification reported by Ayers and Westcot [21], in which water quality-related problems in irrigated agriculture are subdivided into four groups related to:

(1) Salinity: salts in soil or water reduce the water availability to the crop to such an extent that yield is affected;
(2) Water infiltration rate: relatively high sodium or low calcium content of soil or water reduces the rate at which irrigation water enters soil to such an extent that sufficient water cannot be infiltrated to supply the crop adequately from one irrigation to the next;
(3) Specific ion toxicity: certain ions (e.g., sodium, chloride, or boron) from soil or water may accumulate in a sensitive crop to concentrations high enough to cause crop damage and reduce yields;
(4) Miscellaneous: excessive nutrients reduce yield or quality, unsightly deposits on fruit or foliage reduce marketability, and excessive corrosion of equipment increases maintenance and repairs.

2. Rational of Irrigation Water Quality Tool

Although the above-reported classifications are useful and needed for irrigation water sustainable use, analysis of many parameters are expensive and difficult to obtain by farmers, especially in developing countries. In addition, many articulated and too much rigid classifications can reduce the recoverable quantity of water. Therefore, an evaluation of water quality based only on a few crucial parameters (that are able to give good information about the utilization for irrigation and cross the quality aspects with the actual use in terms of irrigated crop species and irrigation systems) can be an easy and flexible method to maximize the low-quality water reuse for agricultural purposes. Under the ACCBAT project (Adaptation to Climate Change through improved water demand management in irrigated agriculture by introduction of new technologies and best agricultural practices), an easily usable irrigation water quality tool (IWQT) to determine the irrigation water use conditions in relation to water quality was developed for Jordan, Tunisia, and Lebanon to increase the use of treated wastewaters and desalinated brackish waters as a water supply source for irrigation.

In these three countries, the use of wastewaters for agriculture is an objective of the national strategies, and investments have been earmarked for the construction of wastewater treatment plants. However, their effective spread in agriculture is still scarce due to the non-optimal quality of this water and the limited means for local institutions to transmit the required expertise to the farmers.

In Tunisia, wastewater reuse in agriculture is regulated by the 1975 Water Code (law No. 75-16 of 31 March 1975), by the 1989 Decree No. 89-1047 (28 July 1989), by the Tunisian standard for the use of treated wastewater in agriculture (NT 106-003 of 18 May 1989), by the list of crops that can be irrigated with treated wastewater (Decision of the Minister of Agriculture of 21 June 1994), and by the list of requirements for agricultural wastewater reuse projects (Decision of 28 September 1995) [22]. As the irrigation of vegetables consumed raw is prohibited, reclaimed wastewater is used to irrigate citrus, olive and other trees, cereals, forages, and industrial crops (sorghum, cotton, tobacco, etc.).

Jordan has the standard JS 893/2006 for the reclaimed water from wastewater treatment plants that is released into streams, valleys (wadis), or water bodies and used for artificial recharge of groundwater aquifers that are not used for drinking purposes or used for restricted agriculture [23].

The thresholds values in both the two countries' standards are in line with the indications reported by Ayers and Westcot [21] and World Health Organization [24].

In Lebanon, wastewater treatment and reuse are not covered by legislation; however, irrigation of vegetables consumed raw is prohibited.

3. The Irrigation Water Quality Tool

To develop the IWQT, the first step was to identify the parameters useful for the evaluation of irrigation water quality able to give good and inexpensive information on the real possibility of its use for crop irrigation.

As reported above, assuming that it is difficult and expensive to monitor all quality parameters with high frequency, only 10 parameters clustered in three quality classes were identified and grouped according to their effects on irrigation:

(1) Agronomic quality indicators: parameters causing toxicity effects on crops or degradation on soil fertility in the medium-long period. The selected key parameters are pH, giving general indications about the quality of the water resource; electrical conductivity (EC), which is one of the major concerns with water used for irrigation; and sodium adsorption ratio (SAR), expressing the toxicity effect on crops and degradation effects on soil fertility.

(2) Hygiene and health quality (sanitary risk) indicators: parameters with no effect on crops yield but dangerous effects on human health due to pathogens transmission, particularly when low-quality water is used to irrigate fresh vegetables. The selected key indicators are: fecal indicator bacteria (*E. coli*), giving general indications about the quality of the water resource, and intestinal nematodos (Helminthes), very dangerous for human health.

(3) Management quality indicators: parameters causing negative effect in irrigation systems (especially clogging) resulting in a low distribution uniformity. The selected key indicators are Total Suspended Solids (TSS), Bicarbonates (HCO_3), Sulphides, Manganese (Mn), and Iron (Fe).

The method, in targeted conditions, can also consider additional indicators, specifically the analysis of heavy metals and metalloids in specific areas, according to local conditions (e.g., rocks or soils are naturally rich of one heavy metal, the water stream passes through an industrial area, etc.).

3.1. The Agronomic Quality Indicators

3.1.1. pH

pH is a chemical parameter that regulates biological functions and can inhibit some biological processes. Soil microorganisms and nutrient conditions are influenced by pH value [25–27] and have to be considered as important parameter when microirrigation is used due to salts precipitation with consequent occlusion problems in the emitters and other components of the system [28,29]. Extreme pH values, especially influencing nutrients availability, affect crop growth and production [30–33]. Furthermore, pH is a key parameter controlling heavy metal transfer behavior in soil where the competition between H^+ and the dissolved metals for ligands becomes more and more significant, decreasing the adsorption abilities and bioavailability of the metals and then increasing their mobility [34]. The increase of heavy metals availability and their potential uptake for crops can have possible phytotoxicity effects and dangerous consequences in the food chain. Singh et al. [35] observed that potential leachability, defined as the maximum metal pool that may become available for leaching at a constant pH 4, decreased in the following order: Zn ~Cd > Mn > Ni > Co > Cu ~As > Pb > Cr.

Although the agricultural soils have a good buffering capacity for stabilizing the pH value [36,37], the use for long time of low quality irrigation water can modify soil pH values [38] and consequently can affect crops production. Therefore, irrigation water pH is a parameter that should be monitored frequently. Zhang et al. [39] proposed using pH as the indicator parameter to assess recycled irrigation water quality because it is easy to access and has a strong correlation with other water chemical characteristics. As is well-known, too high or too low pH values in irrigation water indicate the presence of organic and/or inorganic pollutants.

3.1.2. Electrical Conductivity

High level of EC strictly related to water salinity is one of the main problem especially in the arid and semi-arid Mediterranean areas where abiotic stresses negatively impact crops growth and yield, degrade the land, and pollute groundwater [40–43]. The salt-affected areas amount to some 16 million ha or 25% of the total irrigated land, although detailed information about each country remains scarce, and a deteriorate of situation may be observed in the future due to the effects of climate change on the precipitation, evaporation, runoff, and soil moisture storage [9]. Salinity reduces the plants' water uptake, increasing the osmotic potential and the force to absorb water, decreasing the plants' growth rate, photosynthesis rate, and stomatal conductance [44–49]. The increase in salinity level reduces the photosynthesis rate due to the lower stomatal aperture [50], the depression in specific metabolic processes in carbon uptake [51], the inhibition in photochemical capacity [52], or a combination of these phenomena [53]. Obviously not all crops are equally affected at the same irrigation water salinity due to the different ability to make the needed osmotic adjustments to absorb it. As reported in the FAO paper 29, crops can be classified as tolerant, moderately tolerant, moderately sensitive, and sensitive [21]. In the same paper, the yield potential of the more widespread crops as influenced by irrigation water salinity or soil salinity is reported.

The effects of irrigation with salt waters on crops yield are also influenced by soil type, irrigation methods, irrigation water volumes, and agronomic techniques. Sandy soils are less influenced than clayey soils by the negative effect of sodium, retain less salts distributed with irrigation, and are more easily washed away during rainy seasons.

Also, an adequate irrigation method can limit the negative effects of the use of brackish water: it is recommended to take short irrigation turns to ensure consistently high water availability while at the same time favoring a continuous slow percolation and salt leaching. Drip irrigation is very suitable for this purpose because it allows a prolonged irrigation time and contains at the minimum water losses by evaporation and the increase of salt concentration.

When the build-up of soluble salts in the soil becomes or is expected to become excessive, the soil salt concentration can be controlled by changing the irrigation water volumes. In fact, higher water quantity than that needed by crops during the growing season determine water percolation and salt leaching. The leaching requirement (LR) can be calculated using the following formula [54] based on the principle of constant balance of solutes in soil:

$$\mathrm{LR} = \mathrm{Vd}/\mathrm{Vi} = \mathrm{ECw}/\mathrm{ECd} \tag{1}$$

where LR is expressed as a percentage fraction of the irrigation volume, Vi is the irrigation water volume (m^3), Vd is the drained irrigation water volume (m^3), ECw is the irrigation water electrical conductivity ($dS\ m^{-1}$), and ECd is the maximum value of electrical conductivity in the drainage water tolerated by the crop ($dS\ m^{-1}$). ECd can be regarded as equivalent to the electrical conductivity of the saturated soil extract ECe.

Another equation widely used is [55,56]:

$$\mathrm{LR} = \mathrm{ECw}/((5 \times \mathrm{ECe} - \mathrm{ECw})) \tag{2}$$

The total annual irrigation water quantity (WQ), expressed in mm y^{-1}, to be applied to meet both the crop demand and leaching requirement can be estimated using the equation reported by Ayers and Westcot [21]:

$$\mathrm{WQ} = \mathrm{ET}/((1 - \mathrm{LR})) \tag{3}$$

where ET is the total annual crop water demand (mm y^{-1}).

The measure of EC is not enough to characterize the irrigation water quality considering that soluble ions have different effects on soil and crops. In fact, it does not take into account the salts type which ions can differently influence the colloidal adsorption and desorption phenomenon, with a crucial role on the clay dispersion and soil destructuration. In this context, particular attention must be given to sodium.

3.1.3. Sodium Adsorption Ratio

SAR expresses the toxicity effect of irrigation water on crops and degradation effects on soil fertility due to sodium ions. It is one of the most important parameters for evaluating the characteristics of irrigation water. Although several ions can exert phytotoxic effects on crops with different dangerous level [57], Na and Cl are the most common related to the salinity damages because they can be easily accumulated in plants, where they interfere with physiological, growth, and enzymatic processes [57–62]. The yield reduction due to the high concentration of these ions in the tissues can be related to different reasons, such as:

(1) Reduction in the rate of leaf surface expansion [63];
(2) Accumulation in the leaves of Na with the reduction of the photosynthetic activity and consequently leaves chlorosis and fall [60,64];
(3) Uptake competition with other nutrient ions, especially K^+, Ca^{2+}, and Mg^{2+}, in many crops [65–67];
(4) Late onset of reproductive phase and disruption of the processes involved [68].

As regards the effect on soil properties, the literature shows that the Na concentration in soil layers can affect the dispersion of clay particles [69], the soil water characteristics [70], soil aggregate stability [71], and the formation of soil crusts [72]. Dispersion of soil particles may cause clogging of soil pores, which reduces the soil permeability, soil porosity, and soil water conductivity [73].

The dangerousness of sodium in the irrigation water is evaluated by the SAR (sodium adsorption ratio) index [54]

$$\mathrm{SAR} = \mathrm{Na}/\sqrt{}((\mathrm{Ca} + \mathrm{Mg})/2) \tag{4}$$

where Na, Ca, and Mg are sodium, calcium, and magnesium, respectively (expressed as meq L^{-1}).

3.2. Sanitary Risk Indicators

Low-quality water often contains variety of pathogens that can harm human health. Enteric pathogens, which include viruses, bacteria, protozoa, and helminths, enter the environment in the feces of infected hosts and can enter water either directly through defecation into water, contamination with sewage effluent, or from run-off from soil and other land surfaces [74].

The World Health Organization (WHO) examined the health concerns of wastewater use in agriculture and published microbial water quality guidelines for irrigation water particularly focused on fecal coliforms and intestinal nematodes [75]. As regard the fecal coliform guideline, it was replaced by a focus on attributable risks and disability-adjusted life years (DALYs) as reviewed by Pedrero et al. [19]. The coliform bacteria group includes mainly species of the genus *Citrobacter*, *Enterobacter*, *Escherichia*, and *Klebsiella*. A number of these bacterial pathogens can exert negative effects on human health and also infect or be carried by wild and domestic animals. Among fecal coliforms, *Escherichia coli* is the predominant species, and for this reason, the count of it is the most satisfactory indicator for assessing the quality of wastewater for irrigation use. The WHO recommends the use of water for crops irrigation only if the concentration of fecal coliforms in 100 mL is <1000.

Helminths (nematodes and tape worms) are common intestinal parasites that are transmitted via the fecal-oral route [76]. Helminth parasites commonly detected in wastewaters that are of significant health risk in reused waters include the round worm (*Ascaris lumbricoides*), the hook worm (*Ancylostoma duodenale* or *Necator americanus*), and the whip worm (*Trichuris trichiura*). The close relationship between contaminated wastewater and diseases caused by helminths is well documented [77,78]. Of course, the most serious problems have occurred as horticultural crops. Generally, farmers irrigating with wastewater have higher rates of helminth infections than farmers using fresh water [79,80]. Due to the high dangerousness of this form of contamination, the WHO guideline for water reuse recommends less than 1 intestinal nematode egg L^{-1}. Stabilization ponds constitute a very efficient process for removing all kinds of pathogens. Concerning helminth eggs, sedimentation is the most effective method, which requires a minimum retention time of 5–20 days depending on the initial content [81].

3.3. Management Quality Indicators

Management quality indicators may determine the need to resort to modifications of irrigation and/or require particular irrigation water treatments (e.g., use of filters, sedimentation tanks, etc.).

Physical, chemical, or biological contaminants are closely related to the quality of the water used and can cause clogging of irrigation systems, especially in micro-irrigation devices [28]. The clogging of emitters is one of the more serious problems in drip/trickle irrigation systems causing reduction in application uniformity and negative effects on crops production [82].

The physical contaminants may be: suspended inorganic particles (such as sand and other inorganic debris), organic materials (animal residues and other suspended organic solids), and microbiological debris (algae, etc.) [83]. Even fine clays can clog an emitter by flocculating together to form larger particles. Besides, physical materials can be combined with bacterial slimes [84,85] to form large cluster of debris.

Chemical contaminants can result in problems when they react to form precipitates (e.g., precipitation of calcium carbonate in waters rich in calcium and bicarbonates) [28,86]. Iron and manganese combined with sulphides form a black precipitate that is difficult to treat and remove from the irrigation system [83]. More frequently, the formation of precipitates is related to the oxidized compounds, especially iron precipitates. In fact, iron, present in ferrous form (Fe^{2+}) in groundwater, entering in contact with air is oxidized to ferric iron Fe^{3+}; ferric ions easily react with hydroxyl ions or other anions (e.g., carbonates), giving insoluble compounds.

As regards calcium and magnesium, the possibility to form precipitates of calcium carbonate ($CaCO_3$) or magnesium carbonate ($MgCO_3$) depends on the:

(1) Concentration of HCO_3^- ion;
(2) pH level;
(3) Concentration of calcium, magnesium, sodium and potassium [87].

HCO_3^-, Ca^{2+}, and Mg^{2+} ions are frequently present in irrigation water. The bicarbonates of Ca and of Mg are in solution but they are transformed in insoluble carbonates when the water temperature increases, and evaporation occurs due to solar radiation effect. The reaction is:

$$Ca(HCO_3)_2 \rightarrow \text{drying} \rightarrow CaCO_3 + CO_2 + H_2O \text{ (evaporated)} \quad (5)$$

These precipitates are formed more easily near the emitter orifice, in the form of white limestone, and are deposited progressively up to obstruct the passage of water. Other factors that increase the carbonate precipitation are:

(1) pH higher than 8.0. If the water contains appreciable amounts of Ca or Mg it should be avoid the injection of fertilizers that raise the pH (e.g., Anhydrous ammonia);
(2) High temperature. Carbonates are formed faster in warm water. In fact, the occlusions are more frequent in the pipes exposed to the sun;
(3) Lowering of pressure in the irrigation system. Precipitation can be observed in the filter head during cleaning (backwashing) when the filter is open to atmospheric pressure toward the discharge valve.

Biological clogging is mainly due to the growth of algae and bacterial slimes within the lateral lines and emitters [85,88,89]. In particular, many types of iron bacterium oxidize soluble Fe^{2+} into insoluble Fe^{3+} to form a reddish filamentous slime, while sulphur bacteria may produce a white gelatin slime.

4. Irrigation Water Quality Tool Thresholds and Recommendations

The IWQT was implemented in a spreadsheet composed by different sheets to create a friendly use tool. The IWQT classifies each particular case in one of the following three reference situations:

- Green light (Adequate for irrigation): suitability for use without limitations;
- Yellow light (WARNING! See parameter recommendation sheet): use with caution;
- Red light (Extreme restrictions): severe limitations for irrigation or need.

Based on information found in the cited literature, the quality thresholds for each IWQT parameter were chosen. The list of parameters and their quality thresholds are reported in Table 1.

Table 1. List of parameters used in the Irrigation Water Quality Tool Threshold (IWQT) and their quality thresholds [21,28,75,84,85].

Parameters	Unit Measure	Adequate for Irrigation	Warning	Extreme Restrictions
pH		6.00 ÷ 8.00	5.00–5.99 8.01–9.00	<5.00 >9.00
EC	dS m^{-1}	<0.70	0.70–6.50	>6.50
SAR		<3.00	3.00–9.00	>9.00
E. coli	mean number per 100 mL	<1000		>1000
Intestinal nematodes	arithmetic mean n. of eggs per litre	<1		>1
TSS	mg L^{-1}	<200	200–400	>400
HCO$_3$	mg L^{-1}	<150	150–300	>300
Fe	mg L^{-1}	<0.50	0.50–1.50	>1.50
Mn	mg L^{-1}	<0.10	0.10–1.50	>1.50
H$_2$S	mg L^{-1}	<0.50	0.50–2.00	>2.00

Taking into account the indications given by the scientific literature data, irrigation experts, and personal research experience, a series of recommendations were elaborated to guide farmers on the use of low quality water for irrigation classified in the WARNING categories. When the value of the irrigation water falls in the warning quality thresholds, the IWQT advises to follow specific recommendations reported in a specific sheet.

4.1. pH Recommendations

The pH value influences the soil living and nutrient conditions and should also be considered as an important parameter when microirrigation is used due to salts precipitation and the consequent occlusion problems in the emitters and other components of the system.

Although agricultural soils have a good buffering capacity stabilizing the pH value, the long-time use of irrigation water with low or high pH values can be dangerous for crops production. The following measures should be considered [90] if irrigation water pH is not in the optimal range (6–8):

pH from 8.01 to 9.00

- Increase the quantity of manganese and phosphorus due to their low solubility at high pH values;
- Supply Iron as chelate due to its greater stability and solubility at high pH values;
- Insolubilization and so deficiency of Mn, Zn, Cu, and B can be observed for crops with high requirements provide high quantity of these microelements by fertilization;
- Use fertilizers with acid reaction: ammonium sulphate, mineral superphosphate, double and triple superphosphate, potassium sulphate, and iron sulphate;
- Use low irrigation volume with high number of irrigations to maintain constant high soil moisture. Be careful if irrigation water with high EC is used because this irrigation strategy reduces salts leaching.

pH from 5.00 to 5.99

- Reduce fertilization with microelements for those highly soluble in acid condition. Manganese can determine the phytotoxicity effects;
- Use fertilizers with basic reaction: calcium nitrate, Thomas slag;
- If possible, use high irrigation volume with low number of irrigations to reduce soil moisture. This irrigation strategy further determines a soil EC reduction in the rizosphere zone due to salts leaching.

4.2. EC Recommendations

The Electrical Conductivity (EC) value influences the soil living conditions and crops yield. The use for long time of irrigation water with high EC values can be dangerous for both soil properties and crops production. The following measures [91–94] should be considered if irrigation water EC is not in the optimal range:

EC from 0.7 to 6.5 dS m^{-1}

- Select appropriate salt tolerant crops (see EC relative yield loss sheet where, using data reported in the Table 4 of FAO irrigation and drainage Paper 29 [21], the yield loss was calculated taking into account the water EC and using a linear regression model y = ax + b);
- Do not use overhead sprinkler irrigation because saline water causes leaf damage and can determine yield losses. When possible, prefer night irrigation (low evaporation rate);
- Increase irrigation water supply as in the following formula:

$$\text{Leaching requirement} = EC_{water} \div ((5 \times EC_{soil}) - EC_{water}) \quad (6)$$

  where EC_{water} is the EC of the available irrigation water and EC_{soil} is the soil salinity level.
- Create adequate soil drainage if necessary. This measure is intended to avoid the free movement of water in the root area;
- Soil amendments with gypsum for saline water having Mg:Ca >3 and rich in silica;
- Soil amendments with organic materials;
- Fallowing during the rainy season when irrigation water with high SAR and EC is being used in low-rainfall areas;
- Additional phosphorus application, especially when the $Cl:SO_4$ ratio is >2. Be careful, excessive phosphorus application may be toxic at high salinity;
- Use irrigation water with low EC, if possible, in pre-sowing and at early growth stage;
- Use 20% extra seed and irrigate very soon after sowing (within 2–3 days) to improve germination;
- Remove salts from water with reverse osmosis (if cost-effective).

4.3. SAR Recommendations

The Sodium Adsorption Ratio (SAR) value influences the soil living conditions and crops yield. The use of irrigation water with high SAR values over a long period can be dangerous for soil properties and crops production. The following measures [93] should be considered if irrigation water SAR is not in the optimal range:

SAR from 3.00 to 9.00

- Soils should be sampled and tested every 1–2 years to determine whether the water is causing a sodium increase;
- Do not use overhead sprinkler irrigation because saline water causes leaf damage and can determine yield losses. When possible, prefer night irrigation (low evaporation rate);
- Soil amendments with gypsum for saline water having high SAR value;

- Soil amendments with organic materials;
- Fallowing during the rainy season when irrigation water with high SAR and EC is being used in low-rainfall areas;
- Care should be taken to sensitive crops, including the following: Avocado, Deciduous Fruits, Nuts, Bean, Cotton (at germination), Maize, Peas, Grapefruit, Orange, Peach, Tangerine, Lentil, Groundnut (peanut), Gram, and Cowpeas.

4.4. TSS Recommendations

The Total Suspended Solids (TSS) value influences the production quality and irrigation systems operation. The of irrigation water with high TSS values over a long period of time can result in clogging issues in irrigation systems and the reduction of production quality due to its deposition on leaf and/or fruits and because particles can be related to microbial pollution. The following measures should be considered if irrigation water TSS is not in the optimal range:

TSS from 200 to 400 mg L^{-1}

- Add a filtration system at the control head if a microirrigation system is used. A settling tank/basin before the filtration system is recommended for the higher values;
- Do not use overhead sprinkler irrigation;
- When sand is present, use sand separator systems (e.g., hydrocyclone) to remove most sand contaminants.

4.5. HCO_3 Recommendations

The bicarbonate (HCO_3) values influence the irrigation systems operation and production quality. The long-term use of irrigation water with high HCO_3 values can determine clogging issues in irrigation systems (emitters, sprinkler nozzles, pipes), calcite or lime deposition in the soil, and reduction of production quality due to its whitish deposition on leaves and/or fruits impacted by irrigation water droplets. Irrigation water with high HCO_3 content may contribute to iron chlorosis. Furthermore, high HCO_3 value can increase soil SAR index and pH. The following measures should be considered if irrigation water HCO_3 is not in the optimal range:

HCO_3 from 150 to 300 mg L^{-1}

- Injection of acid (nitric, phosphoric, sulfuric) to dissociate the bicarbonate ions (pH around 6.2) giving off carbon dioxide. It allows the calcium and magnesium to stay in solution in relation with the sodium content. The system may need to be flushed as often as once a week;
- Do not use overhead sprinkler irrigation (when pH is above 8);
- Pay attention to the pressure drop in the irrigation system (especially during the backwash cycle, when the filter is open to atmospheric pressure through the backflush line);
- Bury or shade the lateral lines (calcium carbonate forms faster in warmer water);
- Add gypsum when soils have low free calcium plus leaching;
- Add sulfur to soils with high lime content plus leaching.

4.6. Fe Recommendations

The iron (Fe) values influence the irrigation systems operation and production quality. Chemical precipitation of iron occurs when water is pumped from an aquifer into the irrigation system where the change in environment favors precipitation. The use for long time of irrigation water with high Fe values can be determine clogging issues in irrigation systems (emitters, sprinkler nozzles, pipes), and reduction of production quality due to its deposition on leaf and/or fruits. It is not toxic to plants in aerated soils but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum. The following measures should be considered if irrigation water Fe is not in the optimal range:

Fe from 0.5 to 1.5 mg L^{-1}

- Do not use overhead sprinkler irrigation;
- Do not reach soil water holding capacity;
- Filter iron from water before irrigation system. Fe must first be oxidized to the insoluble form, usually by chlorination to a residual of 1 mg L^{-1} chlorine. An alternative method is aeration in an open pond or by injection of air into the water supply by mechanical devices. This causes oxidized Fe to precipitate. It can then be filtered and removed before the water enters the irrigation line.

4.7. Mn Recommendations

Manganese (Mn) can be toxic to a number of crops at a few-tenths to a few mg L^{-1} but usually only in acid soils (pH below 5) and poorly drained soils. The use of irrigation water with high Mn values can be determine clogging issues in irrigation systems (mostly in emitters). The following measures should be considered if irrigation water Mn is not in the optimal range:

Mn from 0.1 to 1.5 mg L^{-1}

- Do not use overhead sprinkler irrigation;
- Filter Mn from water before irrigation system. Mn must first be oxidized to the insoluble form, usually by chlorination to a residual of 1 mg L^{-1} chlorine. An alternative method is aeration in an open pond or by injection of air into the water supply by mechanical means. This causes oxidized Mn to precipitate. It can then be filtered and removed before the water enters the irrigation line;
- Use fertilizers and/or amendments with basic reaction: calcium nitrate, Thomas slag, and/or gypsum. They must be added in the soil and not as fertirrigation because they can cause precipitation and irrigation system clogging;
- Care should be taken to sensitive crops (Maize, Wheat, Bean, Cotton, and Cowpea).

4.8. H_2S Recommendations

Waters with high concentrations of sulfide anions can cause precipitation and severe clogging problems. Iron and manganese sulfides are very insoluble even in acid solutions. The dissolved sulfide anion can also react with active chlorine when the water is chlorinated so that the effectiveness of the chlorination is reduced. The following measures should be considered if irrigation water H_2S is not in the optimal range:

H_2S from 0.5 to 2.0 mg L^{-1}

- Increase chlorination if used;
- Check the presence of iron and manganese;
- Do not use steel screen filters because interaction with iron can cause iron sulfide precipitation;
- Use a physical aeration, especially at the bottom of stagnant ponds.

5. Conclusions

This study highlighted the possibility to apply a simple tool to evaluate the quality of treated wastewater for crop irrigation and to guide farmers on the use of low-quality irrigation water using specific recommendations to maximize the quantity of recovered water volumes. To reach this aim, the tool for the evaluation of irrigation water quality is based only on few crucial parameters crossed with the crop species and the irrigation system and management. The IWQT was adopted by the

ACCBAT project partners Lebanon, Jordan, and Tunisia, and a Collaboration Agreement on its use was signed in Beirut among the Minister of Agriculture of Lebanon, the Director General of NCARE of Jordan, and the Director at the Direction General for Water Exploitation and Forestry of the Ministry of Agriculture of Tunisia.

Acknowledgments: This work was financed by the ACCBAT project (Adaptation to Climate Change through improved water demand management in irrigated agriculture by introduction of new technologies and best agricultural practices) financed by the European Union (ENPI CBC Mediterranean Sea Basin Programme) through the European Neighborhood and Partnership Instrument. (http://accbat.eu/)

Author Contributions: All authors contributed equally to this work.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. United Nations, Department of Economic and Social Affairs, Population Division. *World Urbanization Prospects: The 2014 Revision, Highlights*; United Nations Publications: New York, NY, USA, 2014.
2. El Mahmoudi, A.S.; Al-Barrak, K.M.; Massoud, M.A. 2-D electrical tomography for mapping of aquifers at the new campus of King Faisl University, Al Hassa, KSA. *Int. J. Water Res. Arid Environ.* **2011**, *1*, 397–410.
3. Abdulla, F.; Eshtawi, T.; Assaf, H. Assessment of the impact of potential climate change on the water balance of a semi-arid watershed. *Water Res. Manag.* **2009**, *23*, 2051–2068. [CrossRef]
4. Cheng, H.; Hu, Y.; Zhao, J. Meeting China's water shortage crisis: Current practices and challenges. *Environ. Sci. Technol.* **2009**, *43*, 240–244. [CrossRef] [PubMed]
5. Sietz, D.; Van Dijk, H. Land-based adaptation to global change: What drives soil and water conservation in western Africa? *Glob. Environ. Chang.* **2015**, *33*, 131–141. [CrossRef]
6. Lesk, C.; Rowhani, P.; Ramankutty, N. Influence of extreme weather disasters on global crop production. *Nature* **2016**, *529*, 84–87. [CrossRef] [PubMed]
7. Ragab, R. Policies and strategies on water resources in the European Mediterranean region. In Proceedings of the Water and Irrigation Development International Conference, Mantova, Italy, 25–27 September 2001; pp. 37–55.
8. FAO (Food and Agriculture Organization of the United Nations) AQUASTAT Database. Available online: http://www.fao.org/nr/water/aquastat/data/query/results.html (accessed on 4 December 2017).
9. Paranychianakis, N.V.; Chartzoulakis, K.S. Irrigation of Mediterranean crops with saline water: From physiology to management practices. *Agric. Ecosyst. Environ.* **2005**, *106*, 171–187. [CrossRef]
10. Levidow, L.; Zaccaria, D.; Maia, R.; Vivas, E.; Todorovic, M.; Scardigno, A. Improving water-efficient irrigation: Prospects and difficulties of innovative practices. *Agric. Water Manag.* **2014**, *146*, 84–94. [CrossRef]
11. Tromboni, F.; Bortolini, L.; Martello, M. The use of water in the agricultural sector: A procedure for the assessment of large-scale irrigation efficiency with GIS. *Irrig. Drain.* **2014**, *63*, 440–450. [CrossRef]
12. Bortolini, L.; Nicoletto, C.; Sambo, P.; Evans, M.R. Radicchio cultivation under different sprinkler irrigation systems. *Contemp. Eng. Sci.* **2016**, *9*, 345–355. [CrossRef]
13. Fader, M.; Shi, S.; Bloh, W.V.; Bondeau, A.; Cramer, W. Mediterranean irrigation under climate change: More efficient irrigation needed to compensate for increases in irrigation water requirements. *Hydrol. Earth Syst. Sci.* **2016**, *20*, 953–973. [CrossRef]
14. Alhumoud, J.M.; Behbehani, H.S.; Abdullah, T.H. Wastewater reuse practices in Kuwait. *Environmentalist* **2003**, *23*, 117–126. [CrossRef]
15. Al-Jasser, A.O. Saudi wastewater reuse standards for agricultural irrigation: Riyadh treatment plants effluent compliance. *J. King Saud Univ. Eng. Sci.* **2011**, *23*, 1–8. [CrossRef]
16. Rattan, R.K.; Datta, S.P.; Chhonkar, P.K.; Suribabu, K.; Singh, A.K. Long-term impact of irrigation with sewage effluents on heavy metal content in soils, crops and groundwater—A case study. *Agric. Ecosyst. Environ.* **2005**, *109*, 310–322. [CrossRef]
17. Masto, R.E.; Chhonkar, P.K.; Singh, D.; Patra, A.K. Changes in soil quality indicators under long-term sewage irrigation in a sub-tropical environment. *Environ. Geol.* **2009**, *56*, 1237–1243. [CrossRef]
18. Zou, J.; Liu, S.; Qin, Y.; Pan, G.; Zhu, D. Sewage irrigation increased methane and nitrous oxide emissions from rice paddies in southeast China. *Agric. Ecosyst. Environ.* **2009**, *129*, 516–522. [CrossRef]

19. Pedrero, F.; Kalavrouziotis, I.; Alarcón, J.J.; Koukoulakis, P.; Asano, T. Use of treated municipal wastewater in irrigated agriculture—Review of some practices in Spain and Greece. *Agric. Water Manag.* **2010**, *97*, 1233–1241. [CrossRef]
20. Raveh, E.; Ben-Gal, A. Irrigation with water containing salts: Evidence from a macro-data national case study in Israel. *Agric. Water Manag.* **2016**, *170*, 176–179. [CrossRef]
21. Ayers, R.S.; Westcot, D.W. *Water Quality for Agriculture*; Food and Agriculture Organization of the United Nations: Rome, Italy, 1994; Volume 29.
22. Angelakis, A.N.; Do Monte, M.M.; Bontoux, L.; Asano, T. The status of wastewater reuse practice in the Mediterranean basin: Need for guidelines. *Water Res.* **1999**, *33*, 2201–2217. [CrossRef]
23. Vallentin, A. Agricultural Use of Reclaimed Water-Experiences in Jordan. *Water Pract. Technol.* **2006**, *1*, wpt2006040. [CrossRef]
24. Blumenthal, U.J.; Mara, D.D.; Peasey, A.; Ruiz-Palacios, G.; Stott, R. Guidelines for the microbiological quality of treated wastewater used in agriculture: Recommendations for revising WHO guidelines. *Bull. World Health Organ.* **2000**, *78*, 1104–1116. [PubMed]
25. Lucas, R.E.; Davis, J. Relationships between pH values of organic soils and availabilities of 12 plant nutrients. *Soil Sci.* **1961**, *92*, 177–182. [CrossRef]
26. Ste-Marie, C.; Paré, D. Soil, pH and N availability effects on net nitrification in the forest floors of a range of boreal forest stands. *Soil Biol. Biochem.* **1999**, *31*, 1579–1589. [CrossRef]
27. Stark, S.; Eskelinen, A.; Männistö, M.K. Regulation of microbial community composition and activity by soil nutrient availability, soil pH, and herbivory in the tundra. *Ecosystems* **2012**, *15*, 18–33. [CrossRef]
28. Capra, A.; Scicolone, B. Water quality and distribution uniformity in drip/trickle irrigation systems. *J. Agric. Eng. Res.* **1998**, *70*, 355–365. [CrossRef]
29. Capra, A.; Scicolone, B. Assessing dripper clogging and filtering performance using municipal wastewater. *Irrig. Drain.* **2005**, *54*, 71–79. [CrossRef]
30. Mahler, R.L.; McDole, R.E. Effect of soil pH on crop yield in northern Idaho. *Agron. J.* **1987**, *79*, 751–755. [CrossRef]
31. Fageria, N.K.; Zimmermann, F.J.P. Influence of pH on growth and nutrient uptake by crop species in an Oxisol. *Commun. Soil Sci. Plant Anal.* **1998**, *29*, 2675–2682. [CrossRef]
32. Anderson, N.P.; Hart, J.M.; Sullivan, D.M.; Hulting, A.G.; Horneck, D.A.; Christensen, N.W. *Soil Acidity in Oregon: Understanding and Using Concepts for Crop Production*; Oregon State University Extension Service: Corvallis, OR, USA, 2013.
33. Cavallaro, V.; Maucieri, C.; Barbera, A.C. *Lolium multiflorum* Lam. cvs germination under simulated olive mill wastewater salinity and pH stress. *Ecol. Eng.* **2014**, *71*, 113–117. [CrossRef]
34. Peng, J.F.; Song, Y.H.; Yuan, P.; Cui, X.Y.; Qiu, G.L. The remediation of heavy metals contaminated sediment. *J. Hazard. Mater.* **2009**, *161*, 633–640. [CrossRef] [PubMed]
35. Singh, S.P.; Ma, L.Q.; Tack, F.M.; Verloo, M.G. Trace metal leachability of land-disposed dredged sediments. *J. Environ. Qual.* **2000**, *29*, 1124–1132. [CrossRef]
36. Xu, R.K.; Zhao, A.Z.; Yuan, J.H.; Jiang, J. pH buffering capacity of acid soils from tropical and subtropical regions of China as influenced by incorporation of crop straw biochars. *J. Soils Sediments* **2012**, *12*, 494–502. [CrossRef]
37. Luo, W.T.; Nelson, P.N.; Li, M.H.; Cai, J.P.; Zhang, Y.Y.; Zhang, Y.G.; Yang, S.; Wang, R.Z.; Wang, Z.W.; Wu, Y.N.; et al. Contrasting pH buffering patterns in neutral-alkaline soils along a 3600 km transect in northern China. *Biogeosciences* **2015**, *12*, 7047–7056. [CrossRef]
38. Hentati, O.; Chaker, S.; Wali, A.; Ayoub, T.; Ksibi, M. Effects of long-term irrigation with treated wastewater on soil quality, soil-borne pathogens, and living organisms: Case study of the vicinity of El Hajeb (Tunisia). *Environ. Monit. Assess.* **2014**, *186*, 2671–2683. [CrossRef] [PubMed]
39. Zhang, H.; Richardson, P.A.; Belayneh, B.E.; Ristvey, A.; Lea-Cox, J.; Copes, W.E.; Moorman, G.W.; Hong, C. Characterization of water quality in stratified nursery recycling irrigation reservoirs. *Agric. Water Manag.* **2015**, *160*, 76–83. [CrossRef]
40. Datta, K.K.; De Jong, C. Adverse effect of waterlogging and soil salinity on crop and land productivity in northwest region of Haryana, India. *Agric. Water Manag.* **2002**, *57*, 223–238. [CrossRef]

41. Ivits, E.; Cherlet, M.; Tóth, T.; Lewińska, K.E.; Tóth, G. Characterisation of productivity limitation of salt-affected lands in different climatic regions of Europe using remote sensing derived productivity indicators. *Land Degrad. Dev.* **2013**, *24*, 438–452. [CrossRef]
42. Qadir, M.; Quillérou, E.; Nangia, V.; Murtaza, G.; Singh, M.; Thomas, R.J.; Drechsel, P.; Noble, A.D. Economics of salt-induced land degradation and restoration. *Nat. Resour. Forum* **2014**, *38*, 282–295. [CrossRef]
43. Butcher, K.; Wick, A.F.; DeSutter, T.; Chatterjee, A.; Harmon, J. Soil salinity: A threat to global food security. *Agron. J.* **2016**, *108*, 2189–2200. [CrossRef]
44. Munns, R. Comparative physiology of salt and water stress. *Plant Cell Environ.* **2002**, *25*, 239–250. [CrossRef] [PubMed]
45. Eisa, S.; Hussin, S.; Geissler, N.; Koyro, H.W. Effect of NaCl salinity on water relations, photosynthesis and chemical composition of Quinoa (Chenopodium quinoa Willd.) as a potential cash crop halophyte. *Aust. J. Crop Sci.* **2012**, *6*, 357.
46. Shabani, A.; Sepaskhah, A.R.; Kamgar-Haghighi, A.A. Growth and physiologic response of rapeseed (*Brassica napus* L.) to deficit irrigation, water salinity and planting method. *Int. J. Plant Prod.* **2013**, *7*, 569–596.
47. Azizian, A.; Sepaskhah, A.R. Maize response to water, salinity and nitrogen levels: Yield-water relation, water-use efficiency and water uptake reduction function. *Int. J. Plant Prod.* **2014**, *8*, 183–214.
48. Simpson, C.R.; Nelson, S.D.; Melgar, J.C.; Jifon, J.; Schuster, G.; Volder, A. Effects of salinity on physiological parameters of grafted and ungrafted citrus trees. *Sci. Hortic.* **2015**, *197*, 483–489. [CrossRef]
49. Kiremit, M.S.; Arslan, H. Effects of irrigation water salinity on drainage water salinity, evapotranspiration and other leek (*Allium porrum* L.) plant parameters. *Sci. Hortic.* **2016**, *201*, 211–217. [CrossRef]
50. Shabala, S.; Munns, R. Salinity stress: Physiological constraints and adaptive mechanisms. In *Plant Stress Physiology*; Shabala, S., Ed.; CABI: Oxfordshire, UK, 2012; pp. 59–93.
51. Chaves, M.M.; Flexas, J.; Pinheiro, C. Photosynthesis under drought and salt stress: Regulation mechanisms from whole plant to cell. *Ann. Bot.* **2009**, *103*, 551–560. [CrossRef] [PubMed]
52. Ashraf, M.; Harris, P.J.C. Photosynthesis under stressful environments: An overview. *Photosynthetica* **2013**, *51*, 163–190. [CrossRef]
53. Ashraf, M. Relationships between growth and gas exchange characteristics in some salt-tolerant amphidiploid Brassica species in relation to their diploid parents. *Environ. Exper. Bot.* **2001**, *45*, 155–163. [CrossRef]
54. Richards, L.A. *Diagnosis and Improvement of Saline and Alkali Soils*; Soil and Water Conservation Research Branch, Agricultural Research Service, US Department of Agriculture: Washington, DC, USA, 1954; p. 160.
55. Rhoades, J.D. Drainage for salinity control. In *Drainage for Agriculture*; Van Schilfgaarde, J., Ed.; American Society of Agronomy: Madison, WI, USA, 1974; pp. 433–462.
56. Rhoades, J.D.; Merrill, S.D. Assessing the suitability of water for irrigation: Theoretical and empirical approaches. In *Prognosis of Salinity and Alkalinity*; Food and Agriculture Organization of the United Nations: Rome, Italy, 1976; pp. 69–110.
57. Shannon, M.C.; Grieve, C.M.; Lesch, S.M.; Draper, J.H. Analysis of salt tolerance in nine leafy vegetables irrigated with saline drainage water. *J. Am. Soc. Hortic. Sci.* **2000**, *125*, 658–664.
58. Allakhverdiev, S.I.; Sakamoto, A.; Nishiyama, Y.; Inaba, M.; Murata, N. Ionic and osmotic effects of NaCl-induced inactivation of photosystems I and II in Synechococcus sp. *Plant Physiol.* **2000**, *123*, 1047–1056. [CrossRef] [PubMed]
59. Flowers, T.J. Improving crop salt tolerance. *J. Exp. Bot.* **2004**, *55*, 307–319. [CrossRef] [PubMed]
60. Parida, A.K.; Das, A.B. Salt tolerance and salinity effects on plants: A review. *Ecotoxicol. Environ. Saf.* **2005**, *60*, 324–349. [CrossRef] [PubMed]
61. Munns, R.; James, R.A.; Läuchli, A. Approaches to increasing the salt tolerance of wheat and other cereals. *J. Exp. Bot.* **2006**, *57*, 1025–1043. [CrossRef] [PubMed]
62. Ghanem, M.E.; van Elteren, J.; Albacete, A.; Quinet, M.; Martínez-Andújar, C.; Kinet, J.M.; Pérez-Alfocea, F.; Lutts, S. Impact of salinity on early reproductive physiology of tomato (*Solanum lycopersicum*) in relation to a heterogeneous distribution of toxic ions in flower organs. *Funct. Plant Biol.* **2009**, *36*, 125–136. [CrossRef]
63. Wang, Y.; Nii, N. Changes in chlorophyll, ribulose bisphosphate carboxylase-oxygenase, glycine betaine content, photosynthesis and transpiration in Amaranthus tricolor leaves during salt stress. *J. Hortic. Sci. Biotechnol.* **2000**, *75*, 623–627. [CrossRef]

64. Agastian, P.; Kingsley, S.J.; Vivekanandan, M. Effect of salinity on photosynthesis and biochemical characteristics in mulberry genotypes. *Photosynthetica* **2000**, *38*, 287–290. [CrossRef]
65. Cramer, G.R.; Epstein, E.; Läuchli, A. Effects of sodium, potassium and calcium on salt-stressed barley. *Physiol. Plant.* **1991**, *81*, 197–202. [CrossRef]
66. Hu, Y.; Schmidhalter, U. Drought and salinity: A comparison of their effects on mineral nutrition of plants. *J. Soil Sci. Plant Nutr.* **2005**, *168*, 541–549. [CrossRef]
67. Tunçtürk, M.; Tunçtürk, R.; Yildirim, B.; Çiftçi, V. Effect of salinity stress on plant fresh weight and nutrient composition of some Canola (*Brassica napus* L.) cultivars. *Afr. J. Biotechnol.* **2013**, *10*, 1827–1832.
68. Kamaluldeen, J.; Yunusa, I.A.; Zerihun, A.; Bruhl, J.J.; Kristiansen, P. Uptake and distribution of ions reveal contrasting tolerance mechanisms for soil and water salinity in okra (*Abelmoschus esculentus*) and tomato (*Solanum esculentum*). *Agric. Water Manag.* **2014**, *146*, 95–104. [CrossRef]
69. He, Y.; DeSutter, T.M.; Clay, D.E. Dispersion of pure clay minerals as influenced by calcium/magnesium ratios, sodium adsorption ratio, and electrical conductivity. *Soil Sci. Soc. Am. J.* **2013**, *77*, 2014–2019. [CrossRef]
70. He, Y.; DeSutter, T.; Casey, F.; Clay, D.; Franzen, D.; Steele, D. Field capacity water as influenced by Na and EC: Implications for subsurface drainage. *Geoderma* **2015**, *245*, 83–88. [CrossRef]
71. Tedeschi, A.; Dell'Aquila, R. Effects of irrigation with saline waters, at different concentrations, on soil physical and chemical characteristics. *Agric. Water Manag.* **2005**, *77*, 308–322. [CrossRef]
72. Bresler, E.; Kemper, W.D. Soil water evaporation as affected by wetting methods and crust formation. *Soil Sci. Soc. Am. J.* **1970**, *34*, 3–8. [CrossRef]
73. Greene, R.S.B.; Rengasamy, P.; Ford, G.W.; Chartres, C.J.; Millar, J.J. The effect of sodium and calcium on physical properties and micromorphology of two red-brown earth soils. *J. Soil Sci.* **1988**, *39*, 639–648. [CrossRef]
74. Toze, S. Reuse of effluent water—Benefits and risks. *Agric. Water Manag.* **2006**, *80*, 147–159. [CrossRef]
75. World Health Organization. *Guidelines for the Safe Use of Wastewater, Excreta And greywater*; World Health Organization: Geneva, Switzerland, 2006; Volume 1.
76. Toze, S. *Microbial Pathogens in Wastewater: Literature Review for Urban Water Systems Multi-Divisional Research Program*; CSIRO: Canberra, Australia, 1997.
77. Hajjami, K.; Ennaji, M.M.; Fouad, S.; Oubrim, N.; Cohen, N. Wastewater reuse for irrigation in Morocco: Helminth eggs contamination's level of irrigated crops and sanitary risk (a case study of Settat and Soualem regions). *J. Bacteriol. Parasitol.* **2013**, *4*, 163.
78. Hajjami, K.; Ennaji, M.M.; Fouad, S.; Oubrim, N.; Khallayoune, K.; Cohen, N. Assessment of helminths health risk associated with reuse of raw and treated wastewater of the Settat City (Morocco). *Res. Environ.* **2012**, *2*, 193–201. [CrossRef]
79. Trang, D.T.; van der Hoek, W.; Cam, P.D.; Vinh, K.T.; Van Hoa, N.; Dalsgaard, A. Low risk for helminth infection in wastewater-fed rice cultivation in Vietnam. *J. Water Health* **2006**, *4*, 321–331. [CrossRef]
80. Trang, D.T.; Van Der Hoek, W.; Tuan, N.D.; Cam, P.D.; Viet, V.H.; Luu, D.D.; Konradsen, F.; Dalsgaard, A. Skin disease among farmers using wastewater in rice cultivation in Nam Dinh, Vietnam. *Trop. Med. Int. Health* **2007**, *12*, 51–58. [CrossRef] [PubMed]
81. Jimenez, B. Helminth ova removal from wastewater for agriculture and aquaculture reuse. *Water Sci. Technol.* **2007**, *55*, 485–493. [CrossRef] [PubMed]
82. Keller, J.; Bliesner, R.D. *Sprinkle and Trickle Irrigation*; AVI Book: New York, USA, 1990; p. 652.
83. Nakayama, F.S.; Bucks, D.A. Water quality in drip/trickle irrigation: A review. *Irrig. Sci.* **1991**, *12*, 187–192. [CrossRef]
84. Bucks, D.A.; Nakayama, F.S.; Gilbert, R.G. Trickle irrigation water quality and preventive maintenance. *Agric. Water Manag.* **1979**, *2*, 149–162. [CrossRef]
85. Gilbert, R.G.; Nakayama, F.S.; Bucks, D.A.; French, O.F.; Adamson, K.C. Trickle irrigation: Emitter clogging and other flow problems. *Agric. Water Manag.* **1981**, *3*, 159–178. [CrossRef]
86. Liu, H.; Huang, G. Laboratory experiment on drip emitter clogging with fresh water and treated sewage effluent. *Agric. Water Manag.* **2009**, *96*, 745–756. [CrossRef]
87. Van der Gulik T.W., B.C. *Trickle Irrigation Manual*; Government of British Columbia: Vancouver, BC, Canada, 1999.

88. Dehghanisanij, H.; Yamamoto, T.; Ahmad, B.O.; Fujiyama, H.; Miyamoto, K. The effect of chlorine on emitter clogging induced by algae and protozoa and the performance of drip irrigation. *Trans. ASAE* **2005**, *48*, 519–527. [CrossRef]
89. Chavan, V.K.; Deshmukh, S.; Nagdeve, M. Mechanism of emitter clogging: A review. In *Wastewater Management for Irrigation: Principles and Practices*; CRC Press: Boca Raton, FL, USA, 2016; p. 37.
90. Enzo, M.; Gianquinto, G.; Lazzarin, R.; Pimpini, F.; Sambo, P. *Principi Tecnico-Agronomici Della Fertirrigazione e del Fuori Suolo*; Tipografia-Garbin: Padova, Italy, 2001.
91. Oster, J.D. Irrigation with poor quality water. *Agric. Water Manag.* **1994**, *25*, 271–297. [CrossRef]
92. Shalhevet, J. Using water of marginal quality for crop production: Major issues. *Agric. Water Manag.* **1994**, *25*, 233–269. [CrossRef]
93. Minhas, P.S. Saline water management for irrigation in India. *Agric. Water Manag.* **1996**, *30*, 1–24. [CrossRef]
94. Beltrán, J.M. Irrigation with saline water: Benefits and environmental impact. *Agric. Water Manag.* **1999**, *40*, 183–194. [CrossRef]