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Treatment and Valorization of Slaughterhouse Wastewater in Agriculture

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ABSTRACT

The reuse of wastewater, after treatment, is part of the country's water resource mobilization and development strategy. In irrigation and compared to conventional resources, the contribution of treated wastewater remains low, accounting for less than 1% of irrigated areas. However, the reuse of treated wastewater can be an important alternative to the use of untreated freshwater in the agricultural sector, particularly in a country like Morocco, where irrigation uses up to 90% of the consumed water. This study aims to assess the effect of treated wastewater reuse on the growth of beans (using stem length and leaf number). The experiment was conducted by irrigating bean plants with four types of water: raw slaughterhouse wastewater, biologically treated water with light, sand-filtered water, and well water used as a control. The effects of these waters on bean development and production were compared to determine the impact of different treatments. The results indicate that irrigation with treated wastewater can be a viable alternative to the use of untreated water in agriculture, particularly in Morocco, where irrigation represents a significant portion of water consumption. However, prior treatment of wastewater, especially that from slaughterhouses, is crucial to avoid negative effects on crop growth. These results highlight the importance of wastewater treatment before reuse, offering a new perspective on the sustainable management of water resources in Morocco.

Keywords: reuse, wastewater, slaughterhouse, treatment, irrigation, beans.

INTRODUCTION

Morocco faces a severe water shortage, characterized by high water stress and a strong dependence on irrigated agriculture. In this context, it is crucial to explore alternative water sources. The reuse of wastewater presents a promising solution to mitigate this shortage. Among these wastewaters, those from slaughterhouses are of particular interest. Slaughterhouses produce specific effluents due to the use of water for washing by-products and disposing of waste such as feces, stomach contents, and blood. Discharge of these effluents untreated into the receiving environment can reduce dissolved oxygen levels, lead to aquatic eutrophication, negatively affect biological life [Ozturk and Yilmaz, 2019], and pose a significant threat to human health [Wei et al., 2011]. These effluents require appropriate treatments, including solid waste and fat separation, as well as aerobic or anaerobic treatments. Complementary processes such as sand infiltration and electrocoagulation are also used to treat these waters [Eric, 2021].

Slaughterhouse wastewater is considered highly polluting due to its high concentrations of organic matter, nitrogen, and phosphorus from suspended solids and colloidal materials such as oils, fats, blood, proteins, and cellulose [Musa et al., 2019]. However, although wastewater treatment methods are well-established, their use in agriculture requires a thorough assessment of their environmental impact. Treated wastewater, while providing nutrients that can reduce fertilization costs, also presents pollution risks [Njiojob and Joël, 2020]. We hypothesize that different wastewater treatment methods will have varied effects on plant growth, with some methods potentially promoting better stem growth and increasing the average number of leaves. This study offers a new perspective on the use of treated wastewater for irrigation, providing crucial data to improve agricultural practices and support water resource management policies in contexts of scarcity.

The aim of this study is to generate new knowledge on the differentiated impact of various types of treated wastewater on plant growth, an area where current data is limited and sometimes contradictory. By precisely comparing stem growth and the average number of leaves of plants irrigated with four distinct types of water, we aim to discover which types of water are most beneficial or potentially harmful to plant growth. This study addresses an important gap by providing empirical evidence on the specific effects of each type of water and proposes hypotheses about the underlying mechanisms of these effects. The expected results will not only clarify the agronomic implications of using treated wastewater but also provide optimized recommendations for its application in agriculture, thus maximizing yields while minimizing environmental risks.

MATERIALS AND METHODS

Sampling

We collected water samples from the discharge of the municipal abattoir of Yacoub Al Mansour in Rabat, which was established in 1956 and covers an area of 1.800 m². This abattoir is one of the traditional municipal abattoirs and is located in one of the most popular districts of the capital (Figure 1). This abattoir was selected primarily due to its accessibility and because it represents a significant source of potential pollution, allowing for a better understanding of the environmental impact of this type of discharge. To assess the environmental impact of the discharges, we collected a total of 16 water samples. The samples were collected over a period of 8 months, at a frequency of twice a month, to account for possible variations in discharges based on different periods and operational conditions of the slaughterhouse. The samples were taken directly from the discharge pipes of the slaughterhouse, at representative collection points to ensure the representativeness of the samples.

Characterization of wastewater discharges

The wastewater from the Rabat slaughterhouse was characterized by various physicochemical parameters (T °C, pH, conductivity, suspended solids, biochemical oxygen demand, chemical oxygen demand). The pH and temperature were determined using a Lutron 206 pH meter equipped with a temperature probe. Electrical

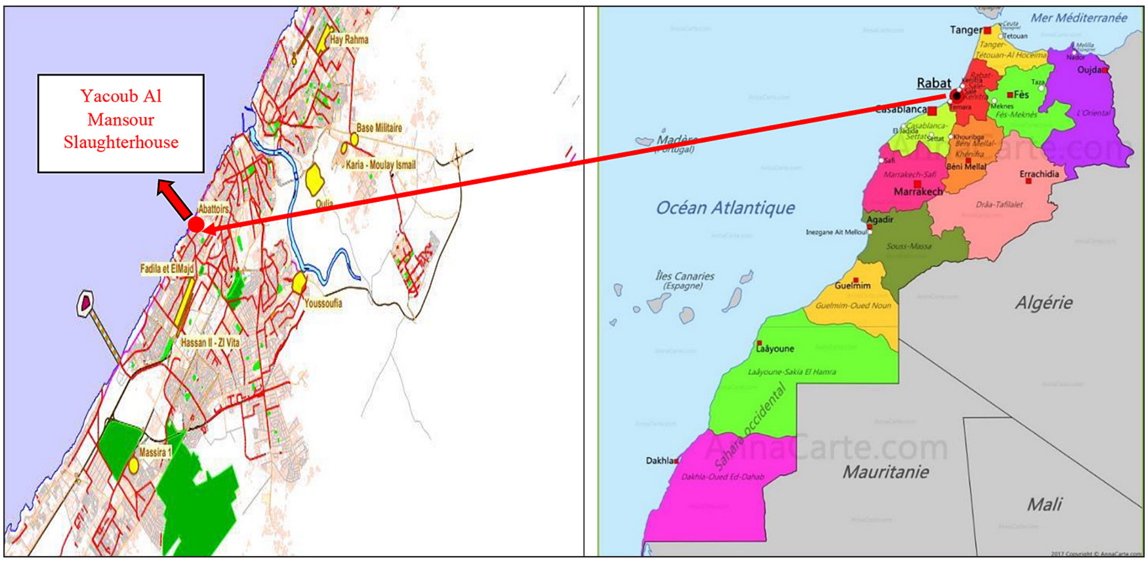

Figure 1. Location of the Yacoub Al Mansour slaughterhouse in the city of Rabat

conductivity was measured using a WTW LF90 conductivity meter, while turbidity was measured using a HACH 21009 turbidimeter. Suspended solids (SS) were determined by filtration through a filter. The organic matter content was determined by evaporating the samples in pre-weighed porcelain capsules. The samples were then dried in an oven at 105 °C, followed by ashing. After conditioning these capsules in an oven at 550 °C, they were cooled and weighed again [Fathallah and Elkharrim, 2013]. Chemical oxygen demand (COD) was determined by oxidation in an acidic medium using excess potassium dichromate at a temperature of 148 °C in the presence of silver sulfate as a catalyst and mercury sulfate [COD, 1992]. Biochemical oxygen demand over 5 days (BOD_5) was determined using the respirometric method with a WTW OXITOP BOD meter, according to the technique described by DIN [1992].

For heavy metals, we conducted analyses of cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), and iron (Fe) for the different types of irrigation water at the National Center for Scientific and Technical Research (CNRST), division : Scientific Research Technical Support Unit (UATRS), in Rabat.

Valorization of abattoir wastewater

This study examines the impact of using both treated and untreated wastewater from the abattoir for irrigating fava bean crops. In addition to the raw abattoir wastewater, treated water obtained through filtration and biological treatment was used. Well water from the EST of Salé served as the control in this experiment. Filtration-treated abattoir water (FW) – A sand filtration process was applied to the raw abattoir wastewater, where a specific quantity of wastewater was passed through a column filled with 13.5 cm of sand and 4 cm of gravel (Figure 2).

Biologically treated water (WTB) – Raw wastewater from the Rabat abattoir was biologically treated by agitating a quantity of wastewater in the presence of light in our laboratory. This treatment can degrade organic matter using microorganisms present in the water [Dhaoudi, 2008] (Figure 3).

The control is irrigated with well water (WW) – The well water used as a control in this study was sampled from the well at the École Supérieure de Technologie de Salé, to ensure a reliable comparison point for bean irrigation and to evaluate contamination levels against a water source unaffected by slaughterhouse discharges.

The soil was collected from a cultivable area within the School of Technology in Salé. We collected soil samples using a lever to fill our pots and planted 5 fava bean seeds in each pot.

Thus, we used four pots (Figure 4) filled with previously sieved soil, using a 2 mm mesh sieve (each pot containing five seeds). Each pot was irrigated with one of the four types of water, with a volume of 80 ml every two days for 8 months. The growth of the plants was then monitored by

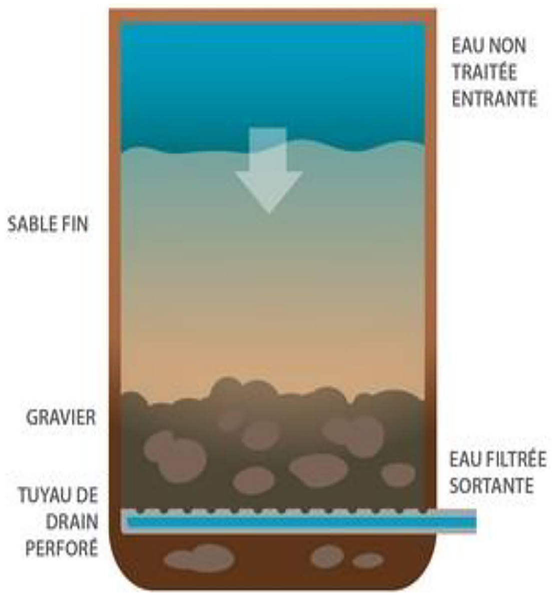

Figure 2. Sand filtration treatment

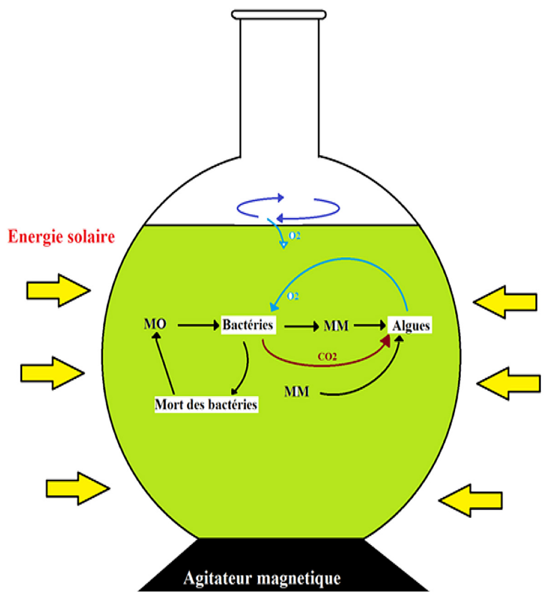

Figure 3. Biological treatment with sunlight

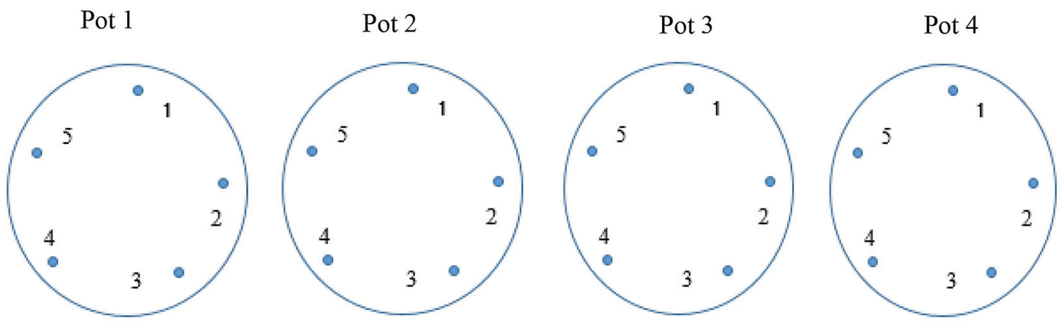

Figure 4. The four fava bean pots irrigated by the four types of irrigation water (Pot 1 : irrigated with raw wastewater. Pot 2 : irrigated with biologically treated water. Pot 3 : irrigated with filtered water. Pot 4 : irrigated with well water)

measuring stem length and counting the number of leaves in each pot.

RESULTS AND DISCUSSION

Physico-chemical quality of different waters intended for irrigation

The four types of water conform to irrigation water standards (Table 1). The temperatures of these waters range from 16.1 °C to 17.9 °C (Table 1). These values remain below the indirect discharge limit for the receiving environment (30 °C). Similarly, these values are considered as indicative limit values for irrigation water (35 °C) [Ministry of the Environment of Morocco, 2002]. In comparison, irrigation waters in the city of Salé [Majdy, 2018] showed similar temperatures, generally below 20 °C, which is also favorable for irrigation.

The pH indicates the alkalinity of wastewater and plays a crucial role in the growth of microorganisms, which generally have an optimum pH range of 6.5 to 7.5. When the pH is below 5 or above 8.5, microorganism growth is directly affected. Additionally, pH is an important factor in interpreting corrosion in the pipes of wastewater treatment facilities [Belghyti et al., 2009]. The pH values remain relatively stable with values ranging from 6.76 to 7.89 (Table 1). These values fall within the Moroccan standards for irrigation water quality and within the limits for indirect discharges [Ministry of the Environment of Morocco, 2002]. The concentrations of total suspended solids (TSS) in the slaughterhouse wastewater range around 960 mg/l, 360 mg/l for the filtered water, and 430 mg/l for biologically treated water (Table 1).

Electrical conductivity is likely one of the simplest and most important parameters for water quality control. It indicates the overall degree of mineralization and provides information about

Table 1. Physico-chemical parameters of waters intended for irrigation

Parameter	Well water (WW)	Filtered water (FE)	Biologically treated water (WTB)	Raw water (RW)	Standards for waters intended for irrigation
pH	7.29	6.91	7.89	6.76	6.5–8.51
T (°C)	17.9	16.1	17.2	16.8	35
Total suspended solids TSS (mg/l)	0.232	360	430	960	2000
Organic matter (mg/l)	7.2	35	145	668	-
Electrical conductivity (CE) mS/cm at 25 °C*	1.178	1.533	1.125	1.296	8.7
Turbidity (NTU)	1	59	181	622	-
Nitrates (mg/l)	10	1.4	3.1	3.5	50
Phosphates (mg PO_4/l)	-	0.0059	0.015	0.081	5
Chlorides (mg/l)	-	190	230	270	350
BOD5 (mg/l)	-	200	322	480	-
COD (mg/l)	-	430	720	1500	-

salinity levels. It is a numerical expression of the water's ability to conduct an electric current, measured in millisiemens per centimeter [Baker et al., 2020]. The conductivity values for the four types of water are : 1.178 mS/cm for WW; 1.533 mS/cm for FW; 1.125 mS/cm for WTB; and 1.296 mS/cm for RW. These values comply with irrigation water standards (12 mS/cm) [Ministry of the Environment of Morocco, 2002].

Turbidity values were recorded at 622 NTU for RW, 59 NTU for FW, 181 NTU for WTB, and 1 NTU for well water. These values also meet irrigation standards [Ministry of the Environment of Morocco, 2002]. These results are consistent with those of Majdy, who reported 353 NTU for RW, 226 NTU for WTB, and 1.33 NTU for WW [Majdy, 2018].

Regarding BOD_5, the values are 200 mg/l for FW and 320 mg/l for WTB, which fall within the range of Moroccan standards as well as those found at the slaughterhouse in Egypte [Condom and Declecq, 2015]. For COD, the values are 430 mg/l for RW and 720 mg/l for WTB. These values are lower than those of Moroccan urban waters (500–1500 mg/L) [ONEP, 1998].

Nitrate concentrations in the treated wastewater from the Rabat slaughterhouse range from 1.4 mg/L to 3.1 mg/L. The increase in these concentrations may result from the organic waste from the slaughterhouse. The levels remain within the standards for irrigation water. These results are comparable to those observed by Khamar [2002] and Zerhouni [2003].

Algae feed on mineral materials such as phosphorus in the form of phosphate, as well as nitrogen (ammonium, nitrates, and gaseous nitrogen), and other mineral elements. This explains the significant decrease in the content of these elements in light-treated water and sand-filtered water [Condom and Declecq, 2015].

The concentrations of Cadmium remain fairly consistent: 0.017 mg/l for RW, 0.014 mg/l for WW, 0.013 mg/l for WTB, and 0.011 mg/l for RW (Table 2). Chromium is present at 0.067 mg/l in RW and at 0.010 mg/l in WW, WTB, and FW. These values are well below the limit for irrigation water (1 mg/l). These results are almost identical to the chromium concentrations found in the irrigation water of the city of Salé, where levels are less than or equal to 0.01 mg/L, a value so low that it is undetectable by the instrument [Majdy, 2018]. Copper concentrations, respectively 0.073 mg/l, 0.037 mg/l, 0.015 mg/l, and 0.033 mg/l for EB, EP, ETB, and EF, also remain below the maximum limit of 2 mg/l for irrigation according to standards [Ministry of the Environment of Morocco. 2002].

The concentrations of iron and lead do not exceed 1.73 mg/l for all four types of water, which complies with Moroccan standards for water quality intended for irrigation [Ministry of the Environment of Morocco. 2002]. Iron and lead concentrations do not exceed 1.73 mg/l for all four types of water. which complies with Moroccan standards for water quality intended for irrigation [Ministry of the Environment of Morocco, 2002].

The average difference in chromium between the different types of irrigation water is statistically significant, with a p-value of 0.00 less than 0.05 for RW and WTB, and $p = 0.002$ for FW. A statistically significant difference ($p < 0.05$) is observed in copper concentrations between FW, WTB, FW, and WW. There is also a significant difference in iron concentrations among the different types of irrigation water. For lead concentrations, there is a statistically significant difference between RW, WTB, and WW ($p = 0.00$, less than 0.05), suggesting that lead concentrations in these three types of water are significantly different. However, there is no statistically significant difference ($p = 0.077$, greater than 0.05) between these waters and filtered water. Zinc concentrations in RW ($p = 0.127$) and FW ($p = 0.74$) do not differ significantly from those observed in WTB and WW. In contrast, biologically treated water (p = 0.007) and well water ($p = 0.00$) show a significant reduction in zinc concentrations.

Table 2. Heavy metals in waters intended for irrigation

Parameter	Well water (WW)	Filtered water (FE)	Biologically treated water (WTB)	Raw water (RW)	Limit values for indirect discharges	Waters intended for irrigation
Cadmium (mg/l)	0.017	0.014	0.013	0.011	0.1	0.01
Chromium (mg/l)	0.067	0.010	0.010	0.010	0.1	1
Copper (mg/l)	0.073	0.037	0.015	0.033	0.1	2
Iron (mg/l)	1.73	0.417	0.663	0.823	-	5
Lead (mg/l)	0.537	0.15	0 .045	0.043	0.2	3.8

These results indicate that biological and filtration treatment significantly reduce the concentration of heavy metals.

Valorization of waters on agricultural development and production

Monitoring of bean stem length irrigated by the four types of water (RW. WW. FW. and WTB)

The monitoring of bean stem growth during the study showed that all four types of irrigation water had a positive influence on stem growth. The length of the bean stem was respectively (79.34 cm) for WW, (66.1 cm) for RW, (95.36 cm) for WTB, and (82.32 cm) for FW (Figure 5). It is observed that the best result is seen in plants irrigated with biologically treated water, which can be explained by mineralization during the decomposition of organic matter into mineral matter. It is also noted that the lowest stem growth is in plants irrigated with raw water. Similarly, the results for the stem lengths of beans irrigated with the three types of water from the city of Salé are as follows : 37.56 cm for RW, 45.5 cm for WTB, and 49 cm for WW. Majdy noted that the yield of crops irrigated with treated wastewater is higher than that of crops irrigated with raw wastewater [Majdy, 2018].

Monitoring of bean leaf count

The monitoring of the number of leaves on beans irrigated with biologically treated water showed a significant increase starting from the 11th week (170 leaves), highlighting the necessity of treating wastewater before its reuse. The nature of leaves irrigated with raw water showed an increase during the study period. However, it was observed that by the end of the 8th week of irrigation, there was a drop in the average number of leaves (Figure 6). To explain this drop, we calculated the amount of total organic matter delivered by the total volume (4560 ml) of raw irrigation water, which was valued at 3046 mg. This high amount could be the cause of the leaf drop on one hand and is probably related to the richness of these waters in nitrates on the other hand. Indeed, at high concentrations, nitrates can lead to leaf drop. The high nitrate content (15.96 mg/l) showed that the water content of NO^{4+} gases is immediately absorbed by the soil. This could be explained by the nitrification of NH^{4+} into NO_2^- and then into NO_3^- during the transit of raw water through the soil [Lhadi et al., 1998].

However, a significant increase in the number of leaves on beans irrigated with well water was observed starting from the 5th week of irrigation, with an average of 138 leaves (Figure 6). Meanwhile, the number of leaves on beans irrigated with sand column filtered water increased by an average of 150 leaves (Figure 6). These results are consistent with those obtained by Majdy, who demonstrated that irrigation with biologically treated water yields the best results for the average number of bean leaves [Majdy, 2018].

To compare the average number of leaves and the average stem length for the four types of irrigation water. The calculated growth rate for the average number of leaves exceeds (97.81%) for WW, (93.54%) for RW, (98.04%) for WTB, and (97.18%) for FW. Similarly, the growth rate for the average stem length of beans exceeds 98%

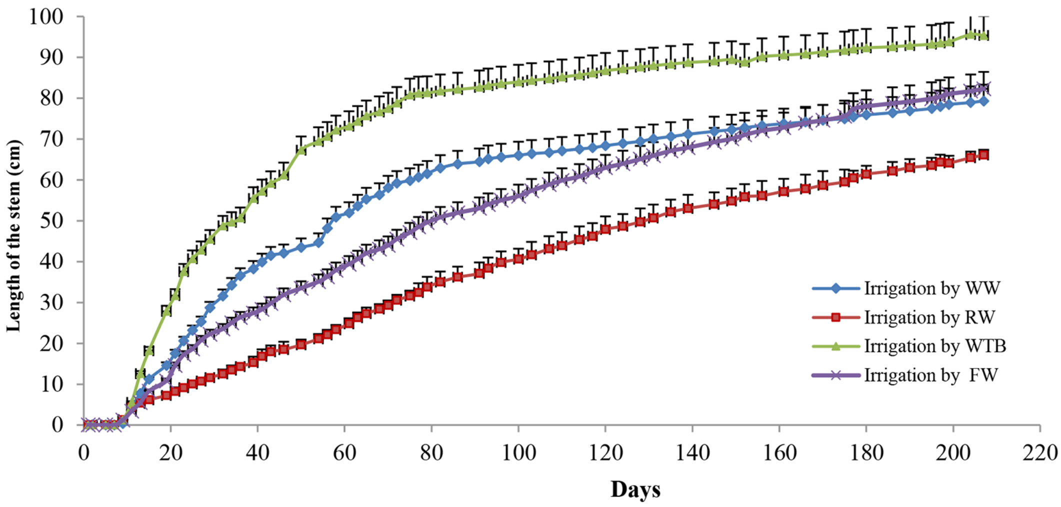

Figure 5. Stem length growth of fava beans irrigated with different types of water (RW, WTB, FW, and WW)

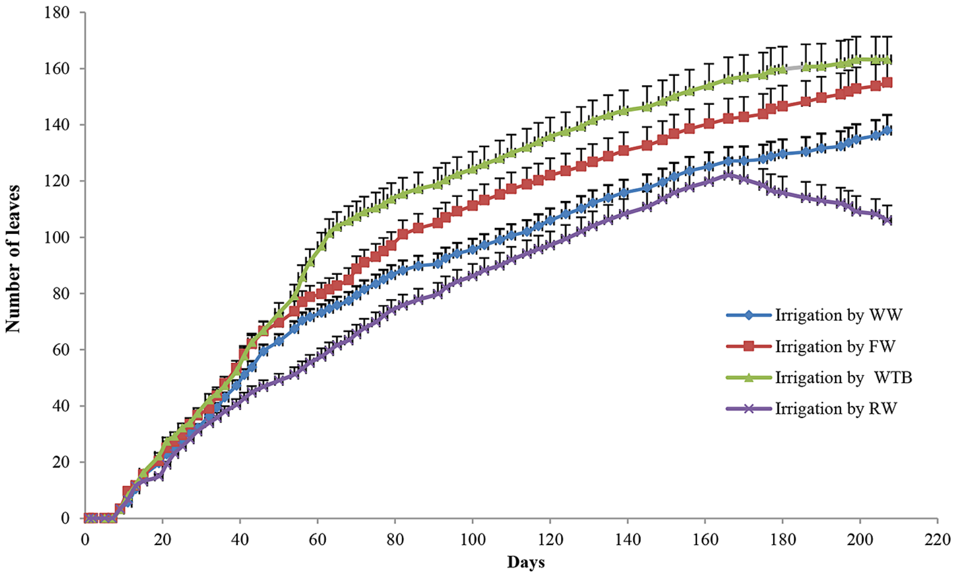

Figure 6. Number of leaves on fava beans irrigated with different types of water (RW, WTB, FW, and WW)

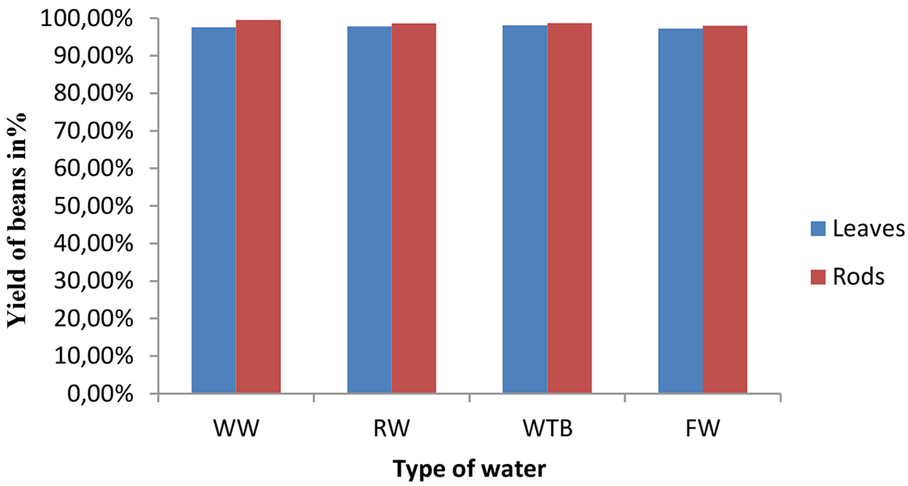

Figure 7. Growth rates of the average number of leaves and stem size of broad beans across the four types of irrigation water (WW, RW, WTB and FW)

for the three types of water, except for the bean stem irrigated with raw water (94.22%) (Figure 7). These results align with Majdy's study, where the growth rate of the average number of leaves exceeds 95% for treated waters (FW and WTB) and reaches 83.22% for RW [Majdy, 2018].

To assess the impact of different irrigation waters (EP, EB, ETB, and EF) on bean growth, we calculated the correlation between the volume of irrigation and two growth parameters: the number of leaves and the stem length. The results show that for stem length, all four types of irrigation water exhibit a significant positive correlation, reaching approximately 99% (Table 3). There is an increase in the number of leaves with the rise in irrigation volume. However, for the number of leaves irrigated with raw wastewater, the curve shows two segments: the first with a positive correlation coefficient and the second where the correlation is negative. This decrease is explained by the leaf drop observed at the 8th week (Figure 8).

The correlation calculated between the number of leaves on fava beans irrigated with ETB and EF and the irrigation volume is positive throughout the study period, except for the plants irrigated with EB. Indeed, the growth of the number of leaves in relation to the irrigation volume shows a positive correlation during the first 8 weeks but becomes negative after the 9th week, which can be attributed to leaf drop. This

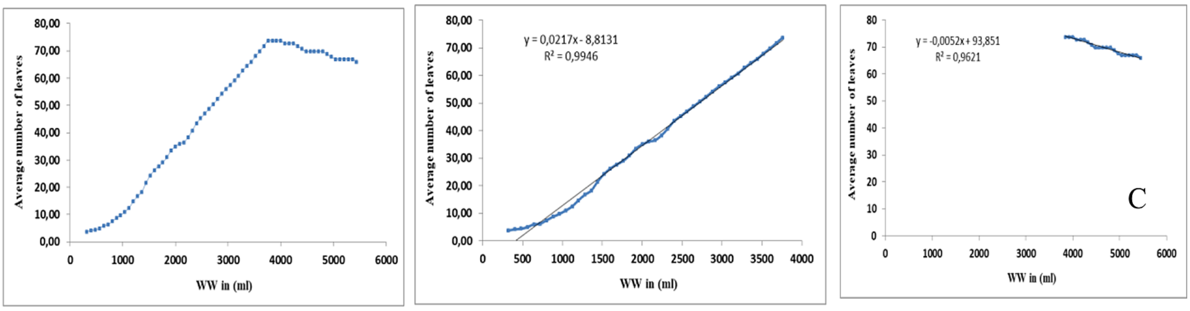

Figure 8. Correlation between the number of leaves on fava beans irrigated with RW and the irrigation volume: (a) monitoring the average number of leaves of fava beans irrigated with eb and the irrigation volume, (b) positive correlation between the average number of leaves of fava beans irrigated with eb and the irrigation volume, (c) negative correlation between the average number of leaves of fava beans irrigated with eb and the volume

Table 3. Correlation coefficients between the number of leaves (Ni) of fava beans and stem length (Li) based on irrigation water (V)

Type of irrigation water	Number of leaves		Stem length	
	Equation	σ en %	Equation	σ en %
RW part 1	Ni = 0.0217 V - 8.8131	99.73	Li = 0.0095 V - 1.2101	99.51
RW part 2	Ni = -0.0052 V + 93.851	98.09		
WW	Ni = 0.0141V + 3.0961	95.39	Li = 0.0101 V + 1.0893	99.55
WTB	Ni = 0.0147V - 2.8056	97.84	Li = 0.009 V - 1.9524	99.84
FW	Ni=0.015V + 0.8645	95.67	Li = 0.0096 V - 0.882	99.58

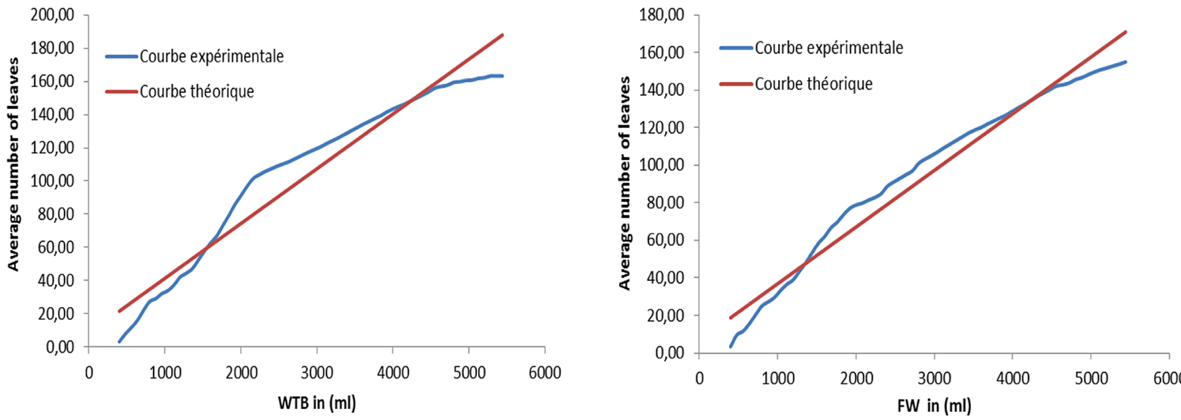

Figure 9. Theoretical and experimental curves of the average number of leaves of fava beans irrigated by WTB and FW

phenomenon may be due to soil clogging caused by the accumulation of organic or mineral residues. The approximation is clearly visible after juxtaposing the experimental and theoretical curves representing the volumes of WTB and FW against the average number of leaves and the average stem length according to the equations Ni = 0.0147 V - 2.8056 for the average number of leaves and Li = 0.009 V - 1.9524 for the average stem length for WTB, and Ni = 0.015 V + 0.8645. Li = 0.0096 V - 0.882 for FW (Figure 9). We observe that the use of treated wastewater from the Rabat slaughterhouse (either biologically or by sand filtration) improves the growth of fava bean leaves. This confirms the necessity of treating wastewater before reusing it in agriculture.

CONCLUSION

This study demonstrated that treated wastewater from the abattoirs in Rabat meets Moroccan standards for irrigation, allowing its reuse in agriculture. Experimental data reveal that beans irrigated with biologically treated or filtered water show superior growth compared to those watered with untreated wastewater. Indeed, treated beans show a notable improvement in terms of the average number of leaves and stem size. In contrast, beans grown with untreated wastewater have an average yield of only 98%, highlighting the significant benefits of pre-treating wastewater.

These results validate the crucial importance of treating wastewater before its use in agriculture. They not only illustrate the ability of treated wastewater to promote optimal plant growth but also its role in sustainable water resource management. This treatment helps bridge the gap between current agricultural practices and the requirements for effective resource management during periods of water scarcity or prolonged drought.

The research also opens up promising perspectives for improving water resource management in contexts of water stress. By promoting the use of treated wastewater, this study contributes to the advancement of sustainable agricultural practices, ensuring both water resource conservation and agricultural productivity. It provides a framework for developing strategies suited to the reuse of wastewater while addressing the growing challenges related to limited water availability in areas subject to extreme climatic conditions.

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