Saudi Journal of Biological Sciences 29 (2022) 2766–2771

Contents lists available at ScienceDirect

Saudi Journal of Biological Sciences

journal homepage: www.sciencedirect.com

Original article

Treated livestock wastewater influence on soil quality and possibilities of crop irrigation

Almas Mukhametov [a,*], Sergey Kondrashev [b], Grigoriy Zvyagin [c], Dmitriy Spitsov [d]

[a] Department of Technology and Safety of Food Products, Kazakh National Agrarian Research University, Almaty, Kazakhstan
[b] Department of Chemistry, Sechenov First Moscow State Medical University, Moscow, Russian Federation
[c] Department of Soil Science and Agrochemistry, S. Seifullin Kazakh Agro Technical University, Nur-Sultan, Kazakhstan
[d] Department of Water Supply and Water Disposal, Moscow State University of Civil Engineering (National Research University), Moscow, Russian Federation

ARTICLE INFO

Article history:
Received 13 September 2021
Revised 22 December 2021
Accepted 28 December 2021
Available online 4 January 2022

Keywords:
Soil
Wastewater
Phosphorus
Hummus
Nitrogen
Salt accumulation
Irrigation

ABSTRACT

This work aims to investigate how livestock wastewater irrigation affects the quality and agricultural potential of soil. The experiments took place in 2019 on a research station with an area of 10 ha (Moscow region, Russian Federation), divided into two even sites of 5 ha (control, experimental). Eleven germination experiments were carried out to determine the influence of livestock wastewater irrigation on radish seeds (1 – control; 10 – irrigation with liquid and solid phases of wastewater samples mixed with pure water). The experimental and control plots appeared to differ in terms of the bulk density of soil. Changes occurred in all horizons ($p \leq 0.05$) but a soil layer with a depth of 0.2–0.4 m. Soil horizons in the experiment plots all exhibited lower porosity ($p \leq 0.05$) except for the topsoil, and the water capacity was higher in the topsoil ($p \leq 0.05$) and near-surface layer ($p \leq 0.05$). The experiment showed higher concentrations of hummus ($p \leq 0.01$) and phosphorus ($p \leq 0.01$). As for nitrogen, significant changes only occurred in the topsoil ($p \leq 0.01$). In the germination experiments, more than 90% of radish seeds germinated. Besides, their root length was higher compared to the control ($p \leq 0.05$). The results of the study suggest that livestock wastewater can benefit crop cultivation after preliminary treatment. Finally, the experiments revealed a reduced soil salt accumulation.

1. Introduction

Due to the increasing volumes of sewage and grey water discharges around the world, it becomes crucial to use them properly (Chaganti et al., 2020). The increase in wastewater volumes depends on multiple factors, such as the level of agriculture development, the level of industrial development, and population size of the given locale (Hajihashemi et al., 2020). One way to make advantage of wastewater is to use it for irrigation purposes (Dragonetti et al., 2020). In this case, the wastewater should meet the following requirements. First, it should increase or maintain the current level of soil fertility. Second, it should be continuously monitored for the content of salt and heavy metals to reduce the likelihood of salinization and avoid transformation into salt marshes (Mkhinini et al., 2020). The reuse of balanced wastewater facilitates the growth of agricultural crops. The wastewater that does not meet those requirements and is impure or lacks the necessary level of microflora undergoes purification.

Wastewater - water that is formed as a result of domestic and industrial human activities, as well as collected in the catchment area of anthropogenic area and subsequently discharged to places of their disposal or runoff. Atmospheric precipitation falling over pristine forests and flowing into rivers does not belong to wastewater, but over public gardens, parks, and quarries it does. Over the past 20 years, according to a March 22, 2021 UN report (UNESCO, 2017), the volume of wastewater in the world has at least doubled. At the same time, most of the increase in runoff came from countries in Africa, Asia, and Latin America with large populations but low levels of economic development.

In countries with a powerful agro-industrial complex (e.g., China, Spain, Brazil), wastewater treatment involves water settling, contaminant removal, advanced filtration (followed by

* Corresponding author.
E-mail addresses: aemukhametov42@rambler.ru, Myhametov_almas@mail.ru (A. Mukhametov).

Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

https://doi.org/10.1016/j.sjbs.2021.12.057
1319-562X/

purification), and conversion to fertilizers (Adhikari, 2014; Ma et al., 2021; Pereira et al., 2011). The most economically convenient method is filtration (Bougnom et al., 2020). Particularly, the irrigation with wastewater containing sugars, starches, and products of hydrolysis was reported to take 5–7 years to pay for itself (Chen et al., 2021). Some cases saw successful reuse of discharged mine water (Ma et al., 2021). The preliminary reclamation of mine land with gypsum, for instance, increased the yield of perennial grasses by 140%, and the treatment of wastewater in the surrounding soil sharply reduced the likelihood of surface water pollution (Farhadkhani et al., 2018). As regards the hydrolysis products (waste from papermaking enterprises), researchers hold that water moving through a layer of soil of 0.7–1.0 m thickness loses its color, odor, and organic matter content. A decline ranges between 5 and 10% (Ma et al., 2021).

The irrigation with wastewater from manufacturing phosphorus fertilizers was reported to improve soil properties and stop alkalinization (Chartzoulakis and Bertaki, 2015). Alkalinization is most often the saturation of soils with sodium salts, causing their pH to rise to values above 7.0. In general, there was a shift in primary soil bases from K and Na to Ca and Mg. Soil fertility did not decrease even after the long-term (5–10 years) irrigation with wastewater from the coke industry (Lahlou et al., 2021). The use of wastewater from a cloth factory led to a 15% increase in fertilization effect and a sharp (60–90%) yield rise compared to the rainfed plots (Bedbabis et al., 2014). In some cases, wastewater is applied to irrigate shelterbelt vegetation. This practice is considered acceptable because tree stands can absorb wastewater impurities (Liang et al., 2021).

Besides the positive aspects of wastewater irrigation, researchers report neutral or even negative experiences. In particular, the irrigation with gas processing wastewaters failed to cause significant changes in the yield of alfalfa or maize but exacerbated soil salinization with chlorides and sulfates (Abbasia and Kamalanb, 2018). The animal feeds made from those crops had elevated concentrations of heavy metals, such as Pb, Cu, Zn, Ni, Mn and Mo (Abbasia and Kamalanb, 2018).

As it can be seen, wastewater irrigation has an ambiguous effect on soil quality and crop yields. In many ways, the ambiguity stems from the unique properties of wastewater (Perulli et al., 2021). Organic and mineral compounds in discharged water provide favorable ground for the growth of microflora. Wastewater can even contain remains of plants or animals. Therefore, farmers tend to prepare wastewater for potential use in irrigation using water settling and filtration methods to remove large debris and coarse solids (Achinas and Euverink, 2016). New industries, however, produce new compounds that are difficult to purify. Wastewater with highly toxic compounds (such as resin and oil) undergoes *chemical treatment*. The techniques include adsorption, hydrolysis, ozonation, chlorination, and coagulation (Lonigro et al., 2015). Of course, chemically treated wastewater will cost more than water exposed to *physical treatment*, but the removal of hazardous compounds should remain a top priority. Wastewater is also subjected to *biological treatment* in specially designed ponds, lagoons, bioreactors and filters. The biological removal of unwanted microflora involves the use of bacteria, protozoa, and rotifers. While purified water is used in irrigation, the dry residues can serve as food additives for use in livestock feed (Lonigro et al., 2015).

More research on wastewater irrigation and its effect on the agricultural potential and quality of soil is needed. While most studies regarding this matter focus on industrial facilities and urban sewage systems (Abbasia and Kamalanb, 2018; Chen et al., 2021; Ma et al., 2021), countries with a strong agro-industrial tradition continue to develop, so does agriculture. This is especially true for countries where agricultural production relies on livestock farming. The livestock industry generates a significant amount of wastewater, often uncontrollably discharged into local water bodies. There is not enough research in this direction (Alavi and Amir-Heidari, 2013; Lyu et al., 2016), and the present paper aims to contribute.

This work is a comprehensive study examining the influence of livestock wastewater use on the growth of agricultural seeds and the physical properties of soil at various depths. The comparison with similar studies will reveal patterns in the rational use of livestock wastewater in irrigation. Hypothetically, regular irrigation with wastewater will increase the contents of humus, nitrogen and phosphorus, which affect the fertility status of soil and, consequently, the yields. The study aims to investigate the effect of livestock wastewater irrigation on the quality and agricultural potential of soil. The objectives of the study are (1) to assess the physical properties of irrigated soil; (2) to measure the contents of humus, N and P in irrigated soil; (3) to examine the salt composition of irrigated soil; and (4) to estimate changes in germinating radish seeds induced by the use of livestock wastewater.

2. Materials and methods

2.1. Materials

The study was conducted in 2019 on a research station with an area of 10 ha. The study area was located within the boundaries of the Russian Academy of Agricultural Sciences experimental farm in the Moscow region (Russian Federation). Five livestock pork farms were surrounding the area. Each farm had separate wastewater tanks. Water used for irrigation came from those reservoirs. The experiments were performed on chernozems with medium and low levels of hummus (3–4%, Table 1). Those and other soil characteristics are presented in Table 1. One crop was cultivated in the experimental plot, namely maize crop. The resulting corn was used for silage.

According to the analysis, the soils were homogenous and consisted mainly of heavy loam with particles clumped into granules. The soils in the experimental plot belonged to the podzolized chernozems. The dry sieving experiment revealed an excellent soil structure. Before irrigation, these soils contained water-resistant aggregates. In addition, a compacted layer was present at a depth of 0.2–0.4 m. The examined chernozems are not susceptible to salinization, and no traces of alkalization were found.

2.2. Research design

In this study, two study areas are compared against each other: an experimental area (5 ha) and a control area (5 ha). The experimental plots were irrigated with livestock wastewater, while the control plots were non-irrigated. The comparison will make it possible to judge the direction and severity of chemical and physical processes triggered by livestock wastewater irrigation. In addition, we conducted a seed germination experiment to confirm or refute the research hypothesis and physicochemical findings. This work was carried out under the international standards of scientific research. The research procedure was approved by the Ethics Committee of the [BLINDED] University (Protocol No. 33-663).

2.3. Research methods

The experimental soils were treated with pre-purified water. In total, the experimental plots were irrigated 8 times with a water supply level of 650 m^3 per ha. The irrigation water was treated with defecate, the waste of sugar beet production. The physical and chemical characteristics of treated wastewater are given in Table 2.

Table 1
Status of hummus (%), mobile compounds (phosphorus, nitrogen, potassium) and heavy metals (*mg/kg*) at different soil profile depth (0–0.4 m).

Depth, m	Humus, %	Phosphorus	Nitrogen	Zinc	Lead	Cadmium	Nickel	Copper
		mg/kg						
0–0.2	4.09	51	5.0	0.79	0.32	0.019	0.55	0.39
0.2–	3.51	40	12.6	–	–	–	–	–
0.4	**3.80**	**45**	**8.9**					
Mean								

All physical and chemical parameters in Table 2 above were obtained using standard methods (granulometric composition, chemical analysis, Salinization parameters). The experimental area was divided into 10 equal plots. Before the experiment, all plots underwent soil surveying to establish the types and depth of soil horizons. Soil pits were made in the centre of each area to measure soil properties in each horizon.

The granulometric composition of the soil was evaluated using sieving and pipette methods. The last step sought to measure the settling velocities of different-sized particles within water and differentiate loam and sandy soils based on that. The chemical analysis was carried out to determine the concentration of heavy metal ions, hummus, phosphorus and nitrogen in the soil samples. Salinization parameters were examined by measuring the concentration of mineral salts present in different layers of soil. Nitrate form of nitrogen was determined in laboratory tests.

Eleven germination experiments on radish seeds (Pink-red variety, Raphanus sativus L. (1753)) were conducted. Experiment 1 included non-treated seeds (control). Other experiments involved using liquid and solid phases of wastewater samples with and without pure water added in various proportions. A limitation of the study is that the results are applicable to wastewater from agricultural farms. Wastewater from other sources of organic or mineral pollution (poultry farms, metallurgical plants, etc.) would be very different in chemical composition from those studied in this work, and therefore would give different results on seed germination.

2.4. Statistical analysis

The data were entered into Excel 2016. Statistical data processing was conducted in Statistica 6.0. The tables present means and levels of significance. The Student's *t*-test (for independent samples) was used to compare the means between the experiment and control groups and between different soil horizons. The maximum level of significance is $p \leq 0.05$.

3. Results

The concentration of heavy metals was within normal limits (Table 1). According to the analysis, irrigation with livestock wastewater has a substantial effect on certain physical and chemical properties of soil (Table 3). For instance, it reduced the specific gravity of soil, but provoked an increase in its bulk density.

The specific gravity of soils in the control group varied significantly between soils depths of 0–0.2 and 0.6–1.0 m ($p \leq 0.05$). The experimental group exhibits significant differences between the topsoil (0–0.2 m soil depth) and depths of 0.2–0.4 and 0.8–1.0 m ($p \leq 0.05$). Differences between the experimental and control groups appear at the 0.4–0.6 ($p \leq 0.05$) and 0.6–0.8 m depths ($p \leq 0.05$). Concerning the bulk density, differences between the two groups are present in the topsoil and two lower layers of the profile (0.6–1.0 m, $p \leq 0.05$). In general, there are significant between-group differences between all soil horizons ($p \leq 0.05$) but the near-surface one (spoil depth of 0.2–0.4 m). Significant differences were found in soil porosity. Soils in the experimental group were less porous within the entire profile ($p \leq 0.05$); the only exception was the soil layer with a depth of 0–0.2 m. The within-group differences between topsoil and lower soil layers (0.6–1.0 m) are significant ($p \leq 0.05$). The water capacity of the soil is higher in the topsoil ($p \leq 0.05$) and the near-surface layer of the profile ($p \leq 0.05$). This observation rings true for both groups.

The bulk density of the soil could increase under the influence of the water from irrigation, which washes large particles away and leads to soil compaction. Besides changes in the physicochemical properties of soil, we recorded an increase in the concentration of hummus, phosphorus and nitrogen (Table 4).

The greatest differences between the groups are their concentrations of hummus ($p \leq 0.01$) and mobile phosphorus ($p \leq 0.01$, Table 4). The level of nitrogen only varies in the topsoil layers ($p \leq 0.01$). The within-group concentrations are also significant ($p \leq 0.05$, Table 4). It rings true for all horizons but those in the soil profile of the experimental plots. Another exception is linked to nitrogen levels. The concentration of hummus in the experimental plots decreased more sharply with depth. Phosphorus was much higher at a depth of 0.2–0.4 m, both in the experimental and control groups. Finally, nitrogen was significantly higher in the topsoil (Table 4).

One indicator that the soil is saline is the amount of solids in it. According to current findings, the irrigated soil samples were not saline (Table 5).

The concentration of salts was generally higher on the soil surface, not at a depth of 0.4 m ($p \leq 0.01$, Table 5). The exceptions are Na^{+}, Cl^{-} and solids. In the lower layer (0.4.-1.0 m), Ca^{2+}, SO_4^{2-}, Cl^{-} and solids were higher at a depth of 1.0 m ($p \leq 0.01$). An increase in cal-

Table 2
Physical and chemical characteristics of treated wastewater.

Parameters	Values	Units	Parameters	Values	Units
pH	6.5	–	Solids	1449	mg/dm^3
Impurities	14.1	%	Bicarbonate anion	829	mg/dm^3
Total nitrogen (TN)	311	mg/dm^3	(HCO_3^-)	229	mg/dm^3
Ammonia nitrogen	211	mg/dm^3	Chlorine anion (Cl^-	74	mg/dm^3
(NH_4-N	18	mg/dm^3	Sulfate anion (SO_4^{2-})	210	mg/dm
Nitrate nitrogen (NO_3-N)	53	mg/dm^3	Calcium cation (Ca^{2+})	67	mg/dm^3
Nitrite nitrogen(NO_2-N)	361	mg/dm^3	Magnesium cation (Mg^{2+})	181	mg/dm^3
Phosphorus oxide (P_2O_5), Potassium oxide (K2O)	377		Sodium cation (Na^+)Minerals	1349	mg/dm^3

Table 3
Changes in physical and chemical characteristics of soil irrigated with livestock wastewater.

Depth, m	Specific gravity of soil (g/cm^3)		Bulk density of soil (g/cm^3)		Soil porosity (%)		Water capacity (%)	
	Control	Experiment	Control	Experiment	Control	Experiment	Control	Experiment
0–0.2	2.66*	2.64*	1.41*,**	1.46*,**	53.5*	52.6*	29.6*,**	30.3*,**
0.2–0.4	2.68	2.63*	1.43	1.46	51.3**	45.4**	28.4**	29.6**
0.4–0.6	2.71*,**	2.66**	1.46**	1.51*,**	50.9**	43.3**	28.4**	28.4*
0.6–0.8	2.72*,**	2.69*	1.51*,**	1.61*,**	49.3*,**	41.6*,**	28.4	28.2*
0.8–1.0	2.73*		1.51*,**	1.66*,**	39.5*,**	38.5*, **	28.3*	28.4*

Note: * – $p \le 0.05$, when layer with a depth of 0–0.2 m is compared with other layers within group; ** – $p \le 0.05$, values are significantly different between groups.

Table 4
The concentration of hummus and mobile compounds (N and P) in soil after livestock wastewater irrigation.

Depth, m	Hummus, %		Nitrogen, mg/kg		Phosphorus, mg/kg	
	Control	Experiment	Control	Experiment	Control	Experiment
0–0.2	4.09*,**	6.66*,**	5.3*,**	10.9*,**	55*,**	65.5**
0.2–0.4	3.51*,**	4.44*,**	13.0*,**	22.6*,**	46*	45.5
0.4–0.6	3.00*,**	3.56*,**	9.2*,**	11.5*,**	50*	49.7

Note: * $p \le 0.05$, when compared within group, ** $p \le 0.01$, when compared between groups.

Table 5
The concentration of salts in soil after livestock wastewater irrigation (in % of the dry soil).

Parameters	Depth, m			
	0–0.4		0.4–1.0	
Solids	0.0331**	0.0571**	0.0461**	0.0694**
HCO_3^-	0.0059**	0.0026**	0.0126	0.0145
Cl^-	0.0071**	0.0099**	0.0050**	0.0169**
SO_4^{2-}	0.0099**	0.025**	0.0157**	0.0274**
Ca^{2+}	0.0039	0.0029	0.0066	0.0077
Mg^{2+}	0.0062**	0.013**	0.0095	0.0088
Na^+	0.0016**	0.0060**	0.0027	0.0017

Note. ** – $p \le 0.01$, values are significantly different between layers.

cium is likely to be associated with a high concentration of $CaCO_3$ in defecate. The same could apply to a decrease in sodium. As regards germination experiments, the best results were obtained in Experiment 4 (Table 6), with a 2:3 pure to waste water ratio.

In Experiment 4, all seeds reached complete germination, and their root length was higher when compared to control ($p \le 0.05$). Similar results were obtained in Experiment 10 ($p \le 0.05$) with a solid phase of wastewater samples mixed with pure water and Experiment 11 without pure water. Note that the use of wastewater gave results that overstepped the standard by 70%, regardless of the type of phase used (Table 6). Therefore, livestock wastewater can be recommended for use in agriculture with preliminary treatment.

4. Discussion

This study noted a change in the physicochemical properties of chernozems. Moreover, the salt composition has changed, so did the content of integral soil components, such as phosphorus, nitrogen, and hummus. Large soil aggregates were washed out of the irrigated soils, causing their aggregate composition to alter. The presence of calcium carbonate slowed down the process of salt

Table 6
Root length and the number of radish seeds that have germinated after wastewater irrigation.

Experiments	Wastewater (parts), cm^3	Pure water (parts), cm^3	Number of radish seeds germinated	Root length, mean, mm	Experiment vs Control, %
Control (non-irrigated)					
Experiment 1	–	5	25*	69*	–
Irrigation, liquid phase					
Experiment 2	1	4	26	71	100 vs 105.1*
Experiment 3	2	3	27	66	96.8 vs 98
Experiment 4	3	2	29*	76*	104.3 vs 112.5
Experiment 5	4	1	30*	72	107.8 vs 106.2
Experiment 6	5	–	23	79*	86.0 vs 116.9
Irrigation, solid phase					
Experiment7	1	4	25	59**	96.8 vs 86.9
Experiment8	2	3	26	60**	89.5 vs 88.4
Experiment9	3	2	27	68	96.6 vs 100.3
Experiment10	4	1	28*	72	100 vs 106.5
Experiment11	5	–	30*	71	108.1 vs 100

Note: * – $p \le 0.05$, values are significantly different from control; ** – $p \le 0.05$, values are significantly different from experimental.

accumulation. The most striking changes in the concentration of active phosphorus took place in the topsoil. A decrease in soil porosity may favor a lower rate of salt accumulation in the soil. This is shown by a specific example where lower salt concentrations were recorded in wastewater irrigated plots compared to controls. At the same time, irrigation with wastewater led to an increase in nitrate nitrogen, phosphorus, and humus. Probably, with long-term preservation of irrigation regime with wastewater of similar chemical composition, there will be a further increase in phosphorus and nitrogen concentration until these elements will not be included in the biological cycle.

Maintaining the concentration of salts and trace elements in the soil is among the primary tasks in modern agrochemistry. The present results show evidence for the successful use of solids from wastewater in radish seed germination. These findings are consistent with other researchers (Al-Zou'by et al., 2017; Kumar et al., 2013). Therefore, the success of using wastewater solids, which usually range from 0.2 to 1.0% of the total volume of wastewater, is associated with the presence of high nitrogen and phosphorus (Al-Tabbal and Ammary, 2014; Jeong et al., 2016).

According to other data, the substantial portion of chemical compounds suitable for plant growth is present not in wastewater solids but in the used water itself (Al-Tabbal et al., 2016; Lado et al., 2012). This assertion appears to be true given the success of Experiment 4.

Some organic substances (e.g., resins and phenols) can harm the environment and human health (Maestre-Valero et al., 2019), but the livestock wastewater did not contain such hazards. Therefore, it is safer to use that type of wastewater in irrigation instead of water discharges from industrial enterprises or urban sewage systems. For higher yields, the furrows that are going to be irrigated must be of equal depth. This requirement will impose some difficulties if the field is located in highly rugged terrain. In this case, some plots will be well irrigated and will give a consistently high yield, and other ones will yield less due to insufficient irrigation (Pereira et al., 2011).

Modern agricultural engineering suggests employing a subsurface irrigation technique to eliminate such disadvantages. In economic terms, however, it is not cheap. Hence, that technology is not popular. This solution can be helpful in enterprises with a closed-loop production system, where it is possible to use water resources multiple times (Morgan, 2011).

Any kind of irrigation, even without wastewater, can be toxic if the soil has already been contaminated with heavy metals. Eventually, they will penetrate different soil horizons and make their way into vegetables and fruits or meat and milk of animals fed with harvested grass. In this study, the heavy metal content of the soil was within the normal range.

Wastewaters are classified depending on their origin, composition, edaphic and climatic conditions (Pedrero et al., 2016). The first category includes wastewaters from light (textile) and heavy industries. Such waters are characterized by a low mineralization degree and can be used in irrigation without preliminary treatment. The second category consists of wastewaters from food industry enterprises. They contain a high amount of organic matter and can be used in irrigation after physical settling. Livestock wastewater can also be attributed to this category because meat-processing enterprises are also part of the food industry. The well-known work suggests mixing wastewater with pure water after the sludge is removed (Morgan, 2011). It seems that this step can also give high results in seed germination. The third category is wastewaters from textile factories. They are suitable for irrigation once the high concentrations of soda are removed. Finally, the last category includes wastewaters from chemical enterprises and those producing synthetic and natural rubbers and synthetic fibres. They are characterized by high concentrations of artificial substances. Therefore, it takes a somewhat long treatment cycle to clean such water (Pedrero et al., 2016).

The situation is slightly different when it comes to treated wastewater plants (wastewater irrigation). Farmers can use water from irrigated fields to grow crops that are not used raw, such as cereals and vegetables subjected to heat treatment, potatoes, and forage plants. The list may also include some berry and fruit crops. With subsurface irrigation, farmers can make no exceptions (Maestre-Valero et al., 2019). Considering that irrigation remains a predominant technique for watering crops, one should take the origin of the crop into account during irrigation, including with livestock wastewater. The present experiment was on radish seeds, but future studies should focus on other vegetable crops and move from a laboratory to the fields. More information about different treated wastewater crops, including their nutritional value, could give a complete picture of wastewater use in irrigation.

5. Conclusions

The treated livestock wastewater should be used after reclamation and agrotechnical measures only. The experimental plots exhibited an increase in the bulk density of the soil and a decrease in its specific gravity. On the other hand, the value of soil porosity in a soil layer with a depth of 0–0.6 m fell by 3% compared to the control. The water capacity changed less dramatically, just by 1.5%, and the change occurred in the topsoil. The wastewater irrigation led to an increase in hummus, nitrate-nitrogen, and active phosphorus. Such changes were observed in a soil layer with a depth of 0–0.4 m. At the same time, the experiment showed greater increases in humus (0.5%) and nitrogen (0.2%). In addition, the experimental plots exhibited a decrease in soil salt accumulation. The likely reason behind this phenomenon is that the defecate used for water treatment contained a large amount (around 80%) of calcium carbonate. In germination experiments, the best results were obtained when wastewater was mixed with pure water. Wastewater solids, however, are also suitable for growing seeds. Based on the study results, the treated livestock wastewater can be used for crop irrigation.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Abbasia, M., Kamalanb, H.R., 2018. Waste management planning in Amirkabir petrochemical complex. Environ. Energy Econ. Res. 2, 63–74. https://doi.org/10.22097/eeer.2018.96582.1011.

Achinas, S., Euverink, G.J.W., 2016. Consolidated briefing of biochemical ethanol production from lignocellulosic biomass. Electron. J. Biotechnol. 23, 44–53. https://doi.org/10.1016/j.ejbt.2016.07.006.

Adhikari, P., 2014. Irrigation with treated wastewater: Quantification of changes in soil physical and chemical properties. J. Irrig. Drain. E-ASCE 03 (01). https://doi.org/10.4172/2168-9768.1000117.

Alavi, N., Amir-Heidari, P., 2013. Effluent quality of ammonia unit in Razi petrochemical complex. J. Adv. Environ. Health Res. 2013 (1), 15–50. https://doi.org/10.22102/jaehr.2013.40120.

Al-Tabbal, J., Al-Zboon, K., Al-Zouby, J., Al-Smadi, B., Ammary, B., 2016. Effect of zeolux use on sage (Salvia officinalis) plant irrigated by fresh and RO reject waters. Glob. Nest J. 18, 416–425. https://doi.org/10.30955/gnj.001569.

Al-Tabbal, J., Ammary, B., 2014. Effect of wastewater and grey water reuse on the germination and early growth of barely and onions. Glob. Nest J. 16, 998–1005.
Al-Zou'by, J.Y., Al-Zboon, K.K., Al-Tabbal, J.A., 2017. Low-cost treatment of grey water and reuse for irrigation of home garden plants. Environ. Eng. Manag. J. 16 (2), 351–359.
Bedbabis, S., Rouina, B.B., Boukhris, M., Ferrara, G., 2014. Effect of irrigation with treated wastewater on soil chemical properties and infiltration rate. J. Environ. Manage. 133, 45–50. https://doi.org/10.1016/j.jenvman.2013.11.007.
Bougnom, B.P., Thiele-Bruhn, S., Ricci, V., Zongo, C., Piddock, L.J.V., 2020. Raw wastewater irrigation for urban agriculture in three African cities increases the abundance of transferable antibiotic resistance genes in soil, including those encoding extended spectrum β-lactamases (ESBLs). Sci. Total Environ. 698, 134201. https://doi.org/10.1016/j.scitotenv.2019.134201.
Chaganti, V.N., Ganjegunte, G., Niu, G., Ulery, A., Flynn, R., Enciso, J.M., Meki, M.N., Kiniry, J.R., 2020. Effects of treated urban wastewater irrigation on bioenergy sorghum and soil quality. Agric. Water Manag. 228, 105894. https://doi.org/10.1016/j.agwat.2019.105894.
Chartzoulakis, K., Bertaki, M., 2015. Sustainable water management in agriculture under climate change. Agric. Agric. Sci. Proc. 4, 88–98. https://doi.org/10.1016/j.aaspro.2015.03.011.
Chen, F.u., Khan, Z.I., Zafar, A., Ma, J., Nadeem, M., Ahmad, K., Mahpara, S., Wajid, K., Bashir, H., Munir, M., Malik, I.S., Ashfaq, A., Ugulu, I., Dogan, Y., Yang, Y., 2021. Evaluation of toxicity potential of cobalt in wheat irrigated with wastewater: health risk implications for public. Environ. Sci. Pollut. Res. 28 (17), 21119–21131. https://doi.org/10.1007/s11356-020-11815-8.
Dragonetti, G., Khadra, R., Daccache, A., Oubelkacem, A., Choukr-Allah, R., Lamaddalena, N., 2020. Development and application of a predictive model for treated wastewater irrigation management in a semiarid area. Integr. Environ. Assess. Manag. 16 (6), 910–919. https://doi.org/10.1002/ieam.4307.
Farhadkhani, M., Nikaeen, M., Yadegarfar, G., Hatamzadeh, M., Pourmohammadbagher, H., Sahbaei, Z., Rahmani, H.R., 2018. Effects of irrigation with secondary treated wastewater on physicochemical and microbial properties of soil and produce safety in a semi-arid area. Water Res. 144, 356–364. https://doi.org/10.1016/j.watres.2018.07.047.
Hajihashemi, S., Mbarki, S., Skalicky, M., Noedoost, F., Raeisi, M., Brestic, M., 2020. Effect of wastewater irrigation on photosynthesis, growth, and anatomical features of two wheat cultivars (Triticum aestivum L.). Water 12 (2), 607. https://doi.org/10.3390/w12020607.
Jeong, H., Kim, H., Jang, T., 2016. Irrigation water quality standards for indirect wastewater reuse in agriculture: A contribution toward sustainable wastewater reuse in South Korea. Water 8, 169. https://doi.org/10.3390/w8040169.
Kumar, N., Bauddh, K., Kumar, S., Dwivedi, N., Singh, D.P., Barman, S.C., 2013. Extractability and phytotoxicity of heavy metals present in petrochemical industry sludge. Clean Technol. Environ. Policy 15 (6), 1033–1039. https://doi.org/10.1007/s10098-012-0559-1.
Lado, M., Bar-Tal, A., Azenkot, A., Assouline, S., Ravina, I., Erner, Y., Fine, P., Dasberg, S., Ben-Hur, M., 2012. Changes in chemical properties of semiarid soils of semiarid soils under long-term secondary treated wastewater irrigation. Soil Sci. Soc. Am. J. 76 (4), 1358–1369. https://doi.org/10.2136/sssaj2011.0230.
Lahlou, F.-Z., Mackey, H.R., Al-Ansari, T., 2021. Wastewater reuse for livestock feed irrigation as a sustainable practice: A socio-environmental-economic review. J. Clean. Prod. 294, 126331. https://doi.org/10.1016/j.jclepro.2021.126331.
Liang, X., Rengasamy, P., Smernik, R., Mosley, L.M., 2021. Does the high potassium content in recycled winery wastewater used for irrigation pose risks to soil structural stability? Agric. Water Manag. 243, 106422. https://doi.org/10.1016/j.agwat.2020.106422.
Lonigro, A., Montemurro, N., Rubino, P., Vergine, P., Pollice, A., 2015. Reuse of treated municipal wastewater for irrigation in Apulia region: The "IN.TE.R.R.A". project. Environ. Eng. Manage. J. 14 (7), 1665–1674. https://doi.org/10.30638/eemj.2015.177.
Lyu, S., Chen, W., Zhang, W., Fan, Y., Jiao, W., 2016. Wastewater reclamation and reuse in China: Opportunities and challenges. J. Environ. Sci. 39, 86–96. https://doi.org/10.1016/j.jes.2015.11.012.
Ma, S., Hu, Y., Zeng, Q., Xu, Z., Cui, Y., Ma, Y., Su, J., Nan, Z., 2021. Temporal changes of calcareous soil properties and their effects on cadmium uptake by wheat under wastewater irrigation for over 50 years. Chemosphere 263, 127971. https://doi.org/10.1016/j.chemosphere.2020.127971.
Maestre-Valero, J.F., González-Ortega, M.J., Martínez-Álvarez, V., Martin-Gorriz, B., 2019. The role of reclaimed water for crop irrigation in southeast Spain. Water Supply 19, 1555–1562. https://doi.org/10.2166/ws.2019.024.
Mkhinini, M., Boughattas, I., Alphonse, V., Livet, A., Gıustı-Mıller, S., Bannı, M., Bousserrhıne, N., 2020. Heavy metal accumulation and changes in soil enzymes activities and bacterial functional diversity under long-term treated wastewater irrigation in East Central region of Tunisia (Monastir governorate). Agric. Water Manag. 235, 106150. https://doi.org/10.1016/j.agwat.2020.106150.
Morgan, K.T., 2011. Effects of reclaimed water on citrus growth and productivity. In: Garcia-Einschlag, F.S. (Ed.), Waste water evaluation and management. Intech Publishers, Rijrka (HR), pp. 325–341.
Pedrero, F., Alarcón, J.J., Nicolás, E., Intriago, J.C., Kujawa-Roeleveld, K., Camposeo, S., Vivaldi, G.A., 2016. Multidisciplinary approach on reclaimed water use projects in agriculture. In: Proceedings of the III Jornada Agua y Sostenibilidad: La Reutilización de Aguas en España y Europa. Pasado, Presente y Futuro; 2016 December 15; Murcia, Spain, pp. 1–13.
Pereira, B.F.F., He, Z.L., Stoffella, P.J., Melfi, A.J., 2011. Reclaimed wastewater: effects on citrus nutrition. Agric. Water Manag. 98 (12), 1828–1833. https://doi.org/10.1016/j.agwat.2011.06.009.
Perulli, G.D., Gaggia, F., Sorrenti, G., Donati, I., Boini, A., Bresilla, K., Manfrini, L., Baffoni, L., Di Gioia, D., Grappadelli, L.C., Spinelli, F., Morandi, B., 2021. Treated wastewater as irrigation source: a microbiological and chemical evaluation in apple and nectarine trees. Agric. Water Manag. 244, 106403. https://doi.org/10.1016/j.agwat.2020.106403.
UNESCO, 2017. Wastewater the new black gold? https://ru.unesco.org/news/stochnye-vody-novoe-chyornoe-zoloto (accessed 17 November 2021).