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The physical and chemical properties of the technosols in the pot experiment with waste and groundwater irrigation

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Abstract. Mediterranean areas are characterized by a strong spatial variability that makes the soil hydrogeological logical response highly complicated. Some seasons provoke dramatic changes in soil properties determining the runoff rates, such as soil water content or soil water repellency. In recent years, important progress has been made in adapting water needs to local conditions through the use of various parameters to assess soil water status. Estimation of the water status of the soil has been widely used in soil science as a tool for quantitative analysis. The main objective of this case study was to analyze technosol and irrigation water physical and chemical properties in the pot experiment with lysimeters. A pot experiment with Avocado rootstocks was equipped with lysimeters in the facilites of the «La Mayora Experimental Field site» of the Higher Council for Scientific Research (Spain). The scheme of the pot experiment included three sources of irrigation: a) groundwater; b) regenerated municipal wastewater (100%); c) a mix of ground and regenerated municipal wastewater (50 / 50%). Chemical analysis data indicate that the reclaimed wastewater does not meet irrigation requirements in terms of pH, EC and due to the significant content of sodium and chlorine. Even groundwater satisfies irrigation water qualitative requirements partially. The suitability of irrigation water on pH level can be characterized mainly as unsuitable and doubtful. Diluting regenerated wastewater with groundwater following the 50% principle led to a decrease in the potential risks for salinization of groundwater connected with leaching of the leachate. The dynamics of the change in the volume of leachate are related to precipitation, the frequency of irrigation, and different manifestations of the physical, mineralogical, and chemical properties of technosols.

Keywords:technosols, pot experiment, lysimeters, groundwater, regenerated water, irrigation

Фізичні та хімічні властивості техноземів у вегетаційному експерименті зі зрошенням стічною та підземною водою

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Анотація. Середземноморські території характеризуються сильною просторовою мінливістю, що робить гідрогеологічну реакцію ґрунту дуже складною. Деякі сезони провокують різкі зміни властивостей ґрунту, що визначають швидкість стоку, наприклад вміст води в ґрунті або водовідштовхувальну здатність ґрунту. За останні роки відбувся важливий прогрес в адаптації потреб у воді до місцевих умов завдяки використанню різних параметрів для оцінки водного стану ґрунту.Основною метою цього тематичного дослідження був аналіз динаміки фізико-хімічних властивостей техноземів та зрошувальної води у вегетаційному експерименті з лізиметрами. Експеримент у посудинах з підщепами авокадо був обладнаний лізиметрами в умовах експериментальної станції в селищі ель Майора підпорядкованій Вищій раді з наукових досліджень (Іспанія). Схема вегетаційного досліду включала три джерела зрошення: а) підземна вода; б) регенеровані міські стічні води(100%); в) суміш підземних і регенерованих міських стічних вод (50/50%). Дані хімічного аналізу свідчать про те, що очищені стічні води не відповідають вимогам поливу за показниками рН, ЕС та через значний вміст натрію та хлору. Навіть підземні води лише частково задовольняють потреби якісного зрошення. Придатність поливної води за рівнем pH можна охарактеризувати переважно як непридатну та сумнівну. Розбавлення регенерованих стічних вод підземними водами за принципом 50% призвело до зниження потенційних ризиків засолення підземних вод, пов'язаних з вимиванням фільтрату. Динаміка зміни об'єму фільтрату пов'язана з випаданням опадів, частотою зрошення і різним проявом фізичних, мінералогічних і хімічних властивостей техноземів.

Ключові слова:техноземи,вегетаційний експеримент, лізиметри, підземна вода, очищена вода, зрошення

Introduction

Precipitations are scarce and erratic and limit water availability for irrigation in Andalusia (Martinez & Blanco, 2019). The climate models create prerequisites addressing different kinds of environmental monitoring and analysis (Blanco, 2017; Bárcena – Martín et al., 2020). Soil water is the link between surface precipitation and groundwater, and plays an important role in the formation, transformation, and consumption of the arid land water resources (Cheng et al., 2020). The hydrological response of soil is defined by: (i) the surface characteristics; (ii) the physical, chemical, and biological properties and (iii) the hydric properties (Hueso-González et al., 2015). Increasing difficulties in securing water demands have led to increased competition for scarce water resources among traditional water user sectors in Andalusian province (Moreno-Pérez & Roldán-Cañas 2013; Roldán-Cañas & Moreno-Pérez, 2021). It becomes more relevant to identify strategies that allow better management of the optimization of water resources, knowing the water balance of the soil, and applying irrigation with recycled water. The soil water balance has traditionally been used to estimate various hydrological parameters of the soil (Wang & Dickinson, 2012) and is essential to understand soil-plant-atmosphere relationships (Hillel, 1998). The water available for vegetation, is related to infiltration and the redistribution and transfer of water (Gabarrón-Galeote et al. al., 2013). The infiltration of water into the soil is conditioned mainly by the texture, the content of organic matter, soil bulk density, vegetation cover and time to runoff (Wood et al., 1987). There is an intermediate soil layer with low humidity between the soil surface and the deeper horizons (Calvo-Cases et al., 2003). In this sense, estimation of the water status of the soil has been widely used in soil science as a tool for quantitative analysis (Scott & Renaud, 2007; Hueso-González et al., 2015). Each soil has characteristic wilting points, field capacity, and saturation, fundamentally dependent on its matrix features and which depend on the texture. This is because the soil texture determines the energy state of the water in the soil matrix (Martínez-Fernández, 1996; Martínez-Fernández & López-Bermudez, 1996; Gomes-Marques et al., 2019).

In Spain, groundwater is used to irrigate over one-third of the total irrigated land (De Stefano et al., 2015). Meantime, groundwater salinization is a serious process affecting coastal aquifers in the south of Spain because seawater and surface water may interact with groundwater in multiple ways (Argamasilla et al., 2017). Reclaimed wastewater is an additional resource for arable land irrigation (Helmecke et al., 2020; Khan et al., 2022, Mishra et al., 2023). It is connected with increasing interest in regions with chronic drought situations, including the avocado-producing areas in the Mediterranean region (Jiménez, 2020). The use of regenerated wastewater for irrigation in water-stressed regions reduces pressure on available natural water resources allowing the use of freshwater for other purposes, improving overall water security (Jodar-Abellan et al., 2019). The application of treated wastewater contains organic matter; essential elements such as N, P, and K; and micronutrients, i.e., Fe, Mn, Zn, and Cu, required for plant growth (Sánchez – González et al., 2017). However, reclaimed wastewater presents a higher chemical complexity than freshwater due to the products that enter the water treatment plants (Salgot et al., 2006) with a higher proportion of nutrients (e.g. N, P, K), soluble salts (such as Cl, Na, Ca, Mg) and organic compounds that could have potential adverse effects on soil quality. It is known that the United Nations (UN) has pushed for the implementation of wastewater reuse all over the world to meet the Sustainable Development Goals (SDGs) by 2030 (United Nations, 2016). Several studies have shown that irrigation with poorly reclaimed wastewater can reduce the soil hydraulic conductivity and (or) soil aggregate stability mainly by biological and physical pore clogging or by high exchangeable sodium levels that induce soil swelling and dispersion effects (Schacht & Marschner, 2015). The quality of the water derived from reclaimed wastewater for irrigation depends on the initial water source, compounds that reach the water treatment plant, treatment grade, and technology and post-treatment dilution (Alcalde-Sanz & Gawlik, 2017). Thus, in order to optimize the management of reclaimed wastewater for irrigation it is necessary to analyze its viability including the presence of salts and other compounds that can affect the structure of the soil to provide suitable irrigation water management practices on a case-by-case basis (Erazo-Mesa et al., 2022; Cárceles Rodríguez et al., 2023).

The main objective of this case study was to analyze technosol and the effect of three irrigation water types: (i) groundwater; (ii) regenerated municipal wastewater (100%) and, (iii) a mix of ground and regenerated municipal wastewater (50 / 50%) on physical and chemical properties in the pot experiment with avocado rootstocks and lysimeters.

Material and methods

Mediterranean areas are characterized by a strong spatial variability that makes the soil hydrological response highly complex (Garbaron-Galeotte et al., 2013). Some seasons provoke dramatic changes in soil properties determining the runoff rates, such as soil water content or soil water repellency.

A pot experiment with Avocado rootstocks was equipped with lysimeters in the facilites of the «La Mayora Experimental Field site» of the Higher Council for Scientific Research (CSIC). Lysimeter facility allows to observe directly water infiltration, storage, and evaporation under well-defined initial and boundary conditions to evaluate and improve infiltration models (Chief et al., 2010).

The soils of the La Mayora experimental station are comprised mostly of black schale substrates and characterize mainly lithosol and fluvisols.The pH value is around 7.1, and the electric conductivity (EC) – 0.68 (dS/m). The soil texture and particle size were determined with «Mastersizer». The soil particle size portion distribution is shown in the figure 1.So, mainly local soil texture can be estimated as silt.

The scheme of the pot experiment included three sources of irrigation: a) groundwater; b) regenerated municipal wastewater (100%); c) a mix of ground and regenerated municipal wastewater (50 / 50%). All substrata were taken in local alluvial deposits. Technosol texture is characterized mainly as silt. Each trial includes 16 vessels. The total number of vessels – 48. The volume of the vessel is 50 liters. The vessel's watering frequency was two times a week and the volume in each watering frequency was 3 liters per vessel.

The pH and electrical conductivity (EC) of the solution were measured using pH and EC meters. The ion content of the water samples was made using the ion chromatography method (Nelson and Sommers, 1996).

The calculation of the suitability of two water sources for irrigation was made using the irrigation coefficient SAR (Sodium Adsorption Ratio):

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}} \quad (1)$$

The interpretation of the SAR and pH data was made following Dr. David Crowley (2008) from the University of California, Riverside, US (Table 1).

Table 1. Suitability of Water for Irrigation

Quality	SAR	pH
Excellent	3	6.5
Good	3-5	6.5-6.8
Permissible	5-10	6.8-7.0
Doubtful	10-15	7.0-8.0
Unsuitable	>15	>8.0

The statistic assessment of the lowest significant difference between the trials of the pot experiment was made using Statistica 6 soft.

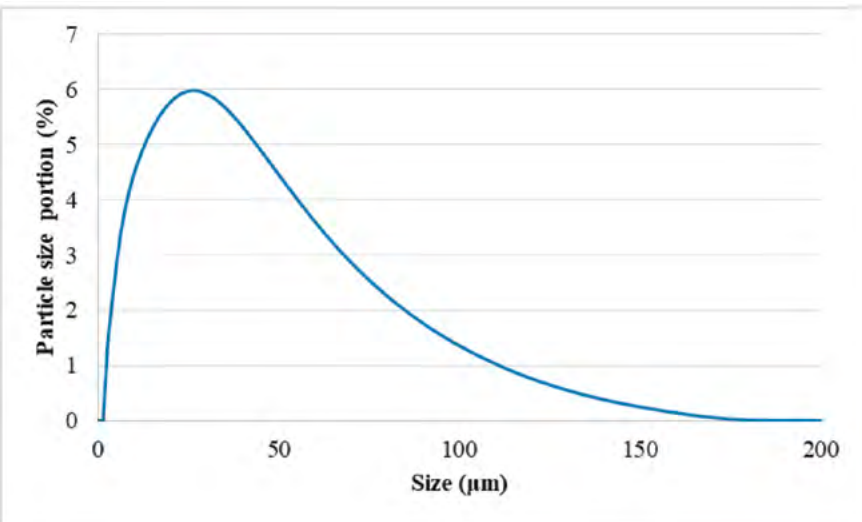

Fig. 1. The soil particle size portion distribution

Results and discussion

The data on pH and electric conductivity (EC) of the two kinds of irrigation water are shown in Table 2

Table 2. pH and electric conductivity of ground and regenerated wastewater

Source	pH	EC (dS/cm)
Groundwater	7.73	1.00
Regenerated wastewater (RWW)	7.51	2.31

The pH of both sources is estimated as doubtful for irrigation. The electric conductivity (EC) of regenerated wastewater is 2.3 times more than groundwater. The data on two kinds of irrigation water cations and anions content are shown in Table 3.

There is an excess of sodium and chloride in wastewater compared to groundwater at 6.5 and 7.4 respectively. The different data on the suitability of two water sources for irrigation have been obtained using the calculation following irrigation coefficient SAR:

$$SAR_{grw} = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}} = 8.0 \quad (2)$$

$$SAR_{ww} = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}} = 51.88 \quad (3)$$

In our case, the SAR of the local regenerated wastewater is 5 times more than 10. That is why the decision was based on the principle of 50% dilution of reclaimed water with groundwater.

The monitoring data on technosol leachates pH at the pot experiment with lysimeters are shown in figures 2-4.

Table 3. The ions content of the two kinds of irrigation water, mg/L

Source	Cl	NO_3	SO_4	Na	K	Mg	Ca
Groundwater	66.64	41.10	116.71	60.89	4.04	56.89	55.71
Regenerated water	495.84	37.92	12709	396.42	32.42	41.58	75.29

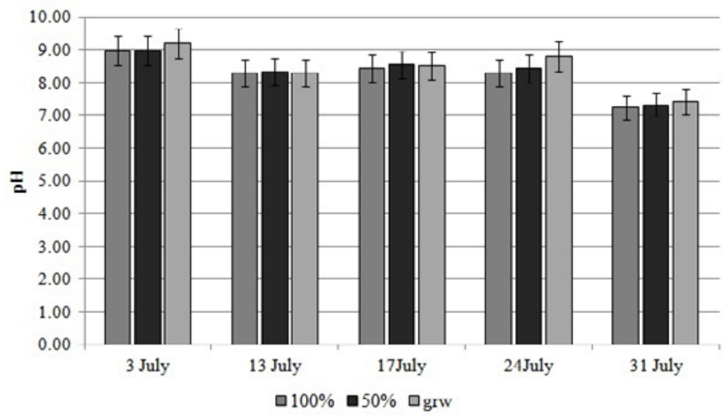

Fig. 2. pH of technosols leachate in July 2023

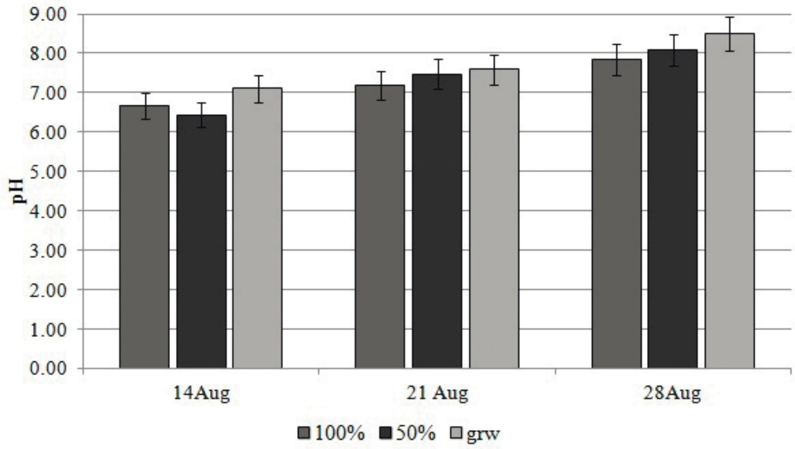

Fig. 3. pH of technosols leachate in August 2023

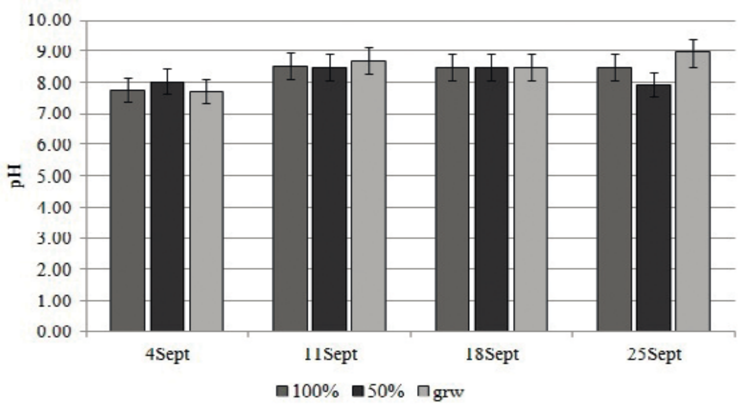

Fig. 4. pH of technosols leachate in September 2023

The data obtained on technosols leachate pH for the 3 months (from July to September 2023) tell us that the suitability of irrigation water on pH level can be characterized regarding Table 1 as follows: a) unsuitable from 3rd of July to 25th of July and doubtful in 31 July; b) good for 50% option, permissible for 100% option and groundwater options on 14 August; c) doubtful during next two weeks of August; d) doubtful in the 4th of September and unsuitable during next three weeks in September 2023.

The monitoring data on technosols leachates electrical conductivity at the pot experiment with three kinds of irrigation water settled in La Mayora Station are shown in figures 5-7.

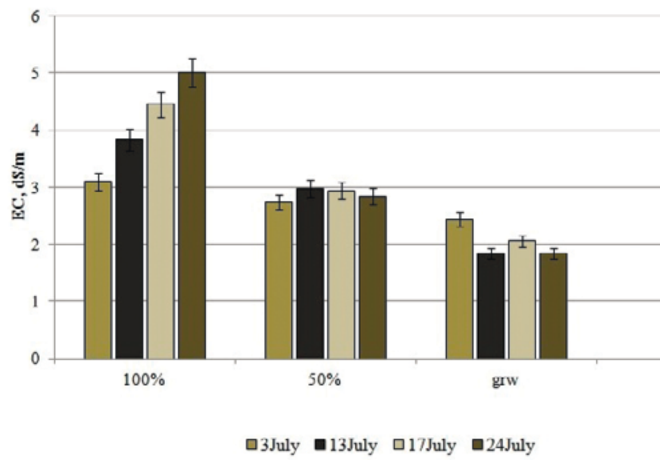

Fig. 5. Electrical conductivity of technosols leachate in July 2023

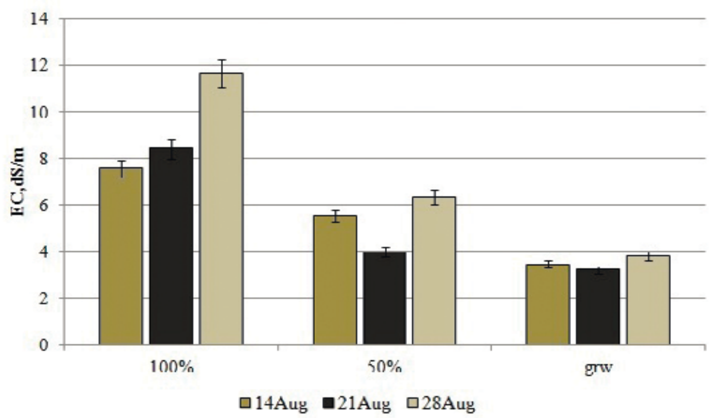

Fig. 6. Electrical conductivity of technosols leachate in August 2023

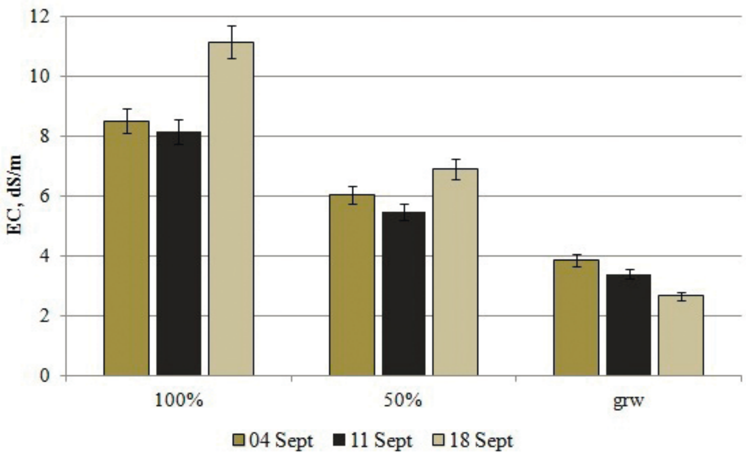

Fig. 7. Electrical conductivity of technosols leachate in September 2023

The data obtained on technosols leachate conductivity for the 3 months (from July to September 2023) tell us that it is possible to decrease the salinity of regenerated wastewater leachate up to 1.5 – 2 times after dissolution with ground water.

Different amounts of applied water had little or no impact on the average root zone salinity (Oster et al., 2007). However, the EC of soil-water samples with a level of 4 dSm^{-1} restricted water uptake. It is known that 4 dS 4 $dSm^{-1} \approx 40$ mM NaCl that many crops are unable to tolerate (Qadir et al., 2000). The EC of technosol leachate in our case was three times larger reaching up to 12 dS/m in the end of August and September in the trial with 100% of regenerated wastewater. Irrigation by the 50% principle reduces potential risks for soil salinization and leaching to the aquifers.

Conclusions

Chemical analysis data indicate that the reclaimed wastewater does not meet irrigation requirements in terms of pH, EC and due to the significant content of sodium and chlorine. Even groundwater satisfies irrigation requirements partially. The suitability of irrigation water on pH level can be characterized mainly as unsuitable and doubtful. Diluting regenerated wastewater with groundwater following the 50/50% principle led to a decrease the potential risks for salinization of groundwater connected with leaching of the leachate.

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