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The effect of municipal treated wastewater on the water holding properties of a clayey, calcareous soil

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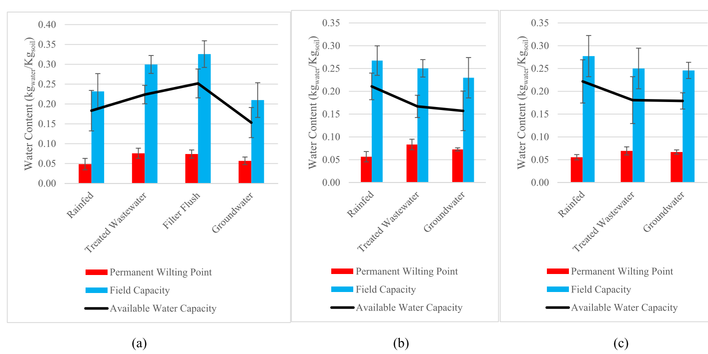
HIGHLIGHTS

- Treated wastewater and brackish groundwater are both potential alternative irrigation sources.
- Field capacity, permanent wilting point, and available water are indicators of a soil's health.
- Treated wastewater and groundwater decreased the soil's water-holding ability in the lower horizons of this soil.
- Treated wastewater not degrades soil properties any more than the groundwater and produces higher yields for the farmer.
- Water conservation solutions should be specific and localized to each region.

GRAPHICAL ABSTRACT

Graphical representation of field capacity, permanent wilting point, and available water capacity for each horizon such that:
(a) Ap horizon = 0 to 15 cm, (b) A horizon = 15 to 30 cm, and (c) B horizon = 30 to 72 cm



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ABSTRACT

Wastewater reuse is a practice that has been gaining attention for the past few decades as the world's population rises and water resources become scarce. Wastewater application on soil can affect soil health, and the manner and extent to which this occurs depends heavily on soil type and water quality. This study compared the long-term (15+ years) effects and suitability of using secondary-level treated municipal wastewater and brackish groundwater for irrigation on the water holding capacity of a clayey, calcareous soil on a cotton farm near San Angelo, Texas. The soil-water holding properties were determined from the extracted hydrostructural parameters of the two characteristic curves: water retention curve and soil shrinkage curve based on the pedostructure concept. In the pedostructure concept, these hydrostructural parameters are characteristic properties of the soil aggregates structure and its thermodynamic interactions with water. Results indicate that use of secondary treated wastewater increased available water capacity in the top horizon (0–15 cm) and decreased the available water holding capacity of this particular soil in the sub-horizons (15–72 cm). The brackish groundwater irrigation resulted in no effect on available water capacity in the top horizon, but significantly decreased it in the sub-horizons as well. The rainfed soil was the healthiest soil in terms of water holding capacity, but rainfall conditions do not produce profitable cotton yields. Whereas, treated wastewater irrigated soil is producing the highest yields for the farmer. Thus, this treated wastewater source and irrigation system can serve as a suitable irrigation alternative to using brackish groundwater, enhancing the water resource sustainability of this region.

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1. Introduction

The future holds many challenges for humanity and its relationship with natural resources, considering population growth, climate change, and the resulting resource competition. Water and food are critical resources for human survival, and soil is at the nexus between human consumption and production of these two resources. Ensuring the environmental, economic, and social sustainability of these resources will require creative, diligent, and localized solutions. West Texas is a semi-arid and sub-tropical region that experiences competition for water between the energy, agriculture, and municipal sectors. In the state of Texas, it is predicted that there will be a 38% water gap by 2050 (2017 Texas State Water Plan), and this plan recommends that reuse makes up for 14.2% of recommended water management strategies to overcome this gap. Treated wastewater (TWW) from municipal wastewater treatment plants has the potential to provide a significant amount of irrigation water for commercial row-crop agriculture, and this is a practice already being employed in the Texas and elsewhere (Arroyo et al., 2011). Brackish groundwater is also an alternative irrigation water source available in west Texas and other regions, which farmers are applying to their soil and crops (George et al., 2011). The environmental and human health impacts of applying different qualities of irrigation water must be evaluated, and the impacts of such practices on soil should be fully understood.

There has been an abundance of research looking at the effects on soil properties of irrigating crops with secondary-level municipal TWW, which involves physical treatment by large filters and settling basins, biological treatment to decrease organic content in the water, and some sort of disinfection. In Texas, the quality criteria for agricultural water reuse from municipal treatment plants is focused on human health concerns related to pathogens and microbes, not any other soil physio-chemical properties. The designation for secondary treated wastewater to be reused for irrigation of non-food crops is termed "Type II" reclaimed water, which has the following quality thresholds by the Texas Commission of Environmental Quality (TCEQ, 2017) (Texas Administrative Code, Rule 210.33) (Table 1).

Coppola et al. (2004) make a case that soil physical and hydrologic characteristics should be considered to define appropriate guidelines for wastewater management, not just chemical and biological. Previous research most relevant to our work includes investigations of soil hydraulic properties including saturated hydraulic conductivity (K_s), infiltration rate, bulk density, porosity, clogging of soil pores, cumulative flow, and water retention.

Tarchitzky et al. (1999) showed that an important effect of adding organic matters (OM) to soil from TWW irrigation is the increase of moisture retention capacity, due to the reduction of soil bulk density and specific surface area of soil particles. Minasny and McBratney, (2018) found that the effect of adding OM to soil does enhance available water capacity, but only modestly. Sandy soils are known to be most responsive to this effect; whereas the effect of OM on water retention in clayey soils was found to be almost negligible. Additionally, Tarchitzky et al. (1999) conclude that dissolved humic substances increases clay dispersion, which makes a case that an increase in sodicity may not be the only driving factor in decreased infiltration rates from TWW irrigation.

Table 1
Type II water quality parameters and limits (Texas Commission on Environmental Quality, 2017) (Reprinted from Texas Administrative Code, Rule 210.33).

Parameter	Limit
BOD 5	20 mg/l
CBOD 5	15 mg/l
Fecal coliform or *E. coli*	200 CFU/100 ml[a]
Fecal coliform or *E. coli*	800 CFU/100 ml[b]
Enterococci	35 CFU/100 ml[a]
Enterococci	89 CFU/100 ml[b]

[a] 30 day geometric mean.
[b] Max. single grab sample.

Three pore space-types have been defined in the soil volume, which were considered: macropore space, which is considered to control aeration and drainage, mesopore space, which is considered to control conductivity, and micropore spaces which are considered to control water retention and available water for plants (Luxmoore, 1981). Luxmoore (1981) defines the micro-, meso-, and macropores in terms of retention and pore diameter ranges. However, it is important to note that this paper will utilize the Pedostructure Concept and Hydrostructural Pedology (Braudeau et al., 2004; Assi et al., 2014; Assi et al., 2017) to define the micro- and macropore spaces as well as available water capacity – these definitions are presented in the methods section.

The general consensus of preceding research, reported in this paragraph, is that TWW irrigation causes a degradation of the soil hydraulic properties. Exceptions to this degradation occur, depending on soil properties like texture. TWW irrigation decreases soil saturated hydraulic conductivity (K_s) across different soil types and textures (Viviani and Iovino, 2004; Abedi-Koupai et al., 2006; Gonçalves et al., 2007; Sepaskhah and Sokoot, 2010; Tarchouna et al., 2010; Assouline and Narkis, 2011; Assouline and Narkis, 2013; Balkhair, 2016; Bardhan et al., 2016; Bourazanis et al., 2016; Gharaibeh et al., 2016). Reduction of K_s was found to be more pronounced in clayey soils, as compared to sandier soils (Viviani and Iovino, 2004; Sepaskhah and Sokoot, 2010) and more pronounced in the upper layer of the soil (<20 cm) (Viviani and Iovino, 2004). Decreases in K_s are likely due to pore clogging of suspended solids in the TWW filling up soil voids (Viviani and Iovino, 2004; Tunc and Sahin, 2015; Gharaibeh et al., 2016;), and a reduced K_s indicates that TWW irrigation affects structural porosity via reducing the macro- and mesopores of the soil structure (Bardhan et al., 2016). The issue of pore clogging and decreased soil K_s could be solved by applying water filtration before irrigation with TWW (Urbano et al., 2017). Further a negative correlation between hydraulic conductivity and both SAR and ESP has been found (Bourazanis et al., 2016). A few exceptions were found in the literature to a decrease of K_s: TWW irrigation caused increased K_s in a silt loam (Vogeler, 2009) and an increased hydraulic conductivity at lower water contents, indicating a change in the soil structure and its microporosity (Gonçalves et al., 2007).

Hydraulic conductivity is highly related to infiltration rates and cumulative flow through the soil medium. TWW irrigation can cause a decrease in infiltration rates or cumulative flow (Assouline and Narkis, 2011; Tunc and Sahin, 2015; Balkhair, 2016; Gharaibeh et al., 2016). However, with sprinkler irrigation TWW irrigation has been found to increase infiltration rate with clays, silty clay, and a silty clay loam using sprinkler irrigation (Abedi-Koupai et al., 2006).

TWW irrigation can have a positive or negative effect on soil moisture and water holding capacity parameters. TWW irrigation has been found to increase overall soil moisture (Hentati et al., 2014; Tunc and Sahin, 2015). For a loamy soil, TWW irrigation caused an increased field capacity, permanent wilting point, and overall available water capacity, due to an increased micropore volume (pressure plate method) (Tunc and Sahin, 2015). Similarly, TWW irrigation caused an increased water retention (as a function of infiltration by using HYDRUS-1-D) in lower layers of a clay (59% content) due to a decreased mean pore radius, but TWW irrigation also caused a decreased water retention capacity for this clay in the top layer of the soil due to an increased mean pore radius (Assouline and Narkis, 2011). A similar decrease in water retention from TWW irrigation was observed in a sandy clay loam (~20% clay) in a disturbed top layer of the horizon, attributed also to a narrowing of pore space (Coppola et al., 2004).

The water retention capacity of a soil should play a significant role in a farmer's irrigation management. Irrigation efficiency is an especially important consideration in arid and semi-arid regions which face competition for water resources among different sectors, especially considering that <65% of applied water is actually being utilized by crops