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EARTH AND ENVIRONMENTAL SCIENCE

NOVEL-RESULT

NEGATIVE-RESULT

Changes in soil hydraulic properties due to organic amendment

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Abstract

The effect of milorganite, a commercially available organic soil amendment, on soil nutrients, plant growth, and yield has been investigated. However, its effect on soil hydraulic properties remains less understood. Therefore, this study aimed to investigate the effect of milorganite amendment on soil evaporation, moisture retention, hydraulic conductivity, and electrical conductivity of a Krome soil. A column experiment was conducted with two milorganite application rates (15 and 30% v/v) and a non-amended control soil. The results revealed that milorganite reduced evaporation rates and the length of Stage I of the evaporation process compared with the control. Moreover, milorganite increased moisture retention at saturation and permanent wilting point while decreasing soil hydraulic conductivity. In addition, milorganite increased soil electrical conductivity. Overall, milorganite resulted in increased soil moisture retention; however, moisture in the soil may not be readily available for plants due to increased soil salinity.

Key words: electrical conductivity; evaporation rate; milorganite; moisture retention

Introduction

Allen et al. (1998) observed that soil surface evaporation is a function of the mean water content in the topsoil (10–15 cm). However, several studies have reported that the evaporation process is characterized by multiple stages (Figure 1). The first stage (Stage I) is when the evaporation rate is constantly followed by a second stage (Stage II) characterized by a decreasing rate of evaporation (Metzger & Tsotsas, 2005). As surface soil continues to dry, during Stage I, water from the deeper soil is supplied to the surface soil by capillary flow to maintain a constant evaporation rate (Lehmann et al., 2018; Shokri & Or, 2011). As the soil becomes drier, capillary pathways will be disrupted and the evaporation rate drops significantly at Stage II (Shokri et al., 2008). An investigation by An et al. (2018) revealed that during Stage I, soil-water content decreased continuously with time; however, the ratio of actual to potential evaporation (AE/PE) remained stable. Subsequently, during Stage II, AE/PE decreased significantly. Reports showed that the evaporation rate during Stage II is driven by vapor diffusion across the dry soil profile, which increases at a rate inversely proportional to the square root of time (Brutsaert, 2014; Or et al., 2013).

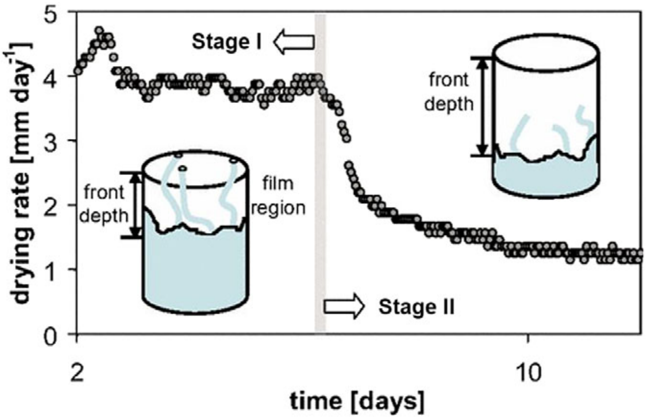

Figure 1. Schematic of the evaporation stages of a drying soil (adapted from Lehmann et al., 2008).

Several studies have reported that biosolids and organic amendments enhance soil hydraulic properties, which in turn have positive impacts on soil and water relations including water retention and infiltration (Babalola et al., 2012; Bayabil et al., 2015; Brye et al., 2005; Mohamed Am et al., 2010; Page-Dumroese et al., 2018; Rahman et al., 1996). However, there is no clear understanding of whether increased moisture retention due to organic amendments would lead to increased evaporation losses. It is expected that as more moisture is available within the topsoil due to organic amendment, the evaporation rate could potentially increase compared to non-amended control soils. A 75 g/kg rice barn or fish meal application to saline soils also reduced evaporation by 8–20% (Chang et al., 2016). Adeyemo et al. (2019) observed that the incorporation of 10 Mg/ha of poultry manure led to a reduction in cumulative infiltration rates for sandy soils. Milorganite is a commercially available product produced from sewage sludge treatment plants and is used as a soil amendment (Kebrom et al., 2019; Staufenbeil, 2019). Milorganite could potentially serve as a slow-release fertilizer as it contains more than 6% nitrogen and 4% phosphorous by mass. For example, the application of milorganite increased the content of soil inorganic nitrogen and maintained soil microbial biomass (Wang et al., 2020). Hence, the objective of this study was to investigate the poorly studied effects of milorganite on soil moisture characteristics, hydraulic conductivity, and evaporation rates. The study hypothesis was that the addition of milorganite to the soil will affect the moisture characteristics, hydraulic conductivity, and evaporation rates of the soil.

Materials and methods

Soil and milorganite

Krome soil was collected from research fields at the Tropical Research and Education Center in Homestead, Florida, USA. Then the soil was sieved using a 2-mm sieve to remove coarse materials. The selected properties of both soil and milorganite are presented in Table 1.

Experimental design

The experiment was designed with three treatments in three replicates: control (no milorganite), 15% v/v milorganite, and 30% v/v milorganite. The study was conducted in a greenhouse using PVC columns (10-cm diameter and 1,178-cm^3 volume). The 2-mm sieved soil was mixed uniformly with two rates of milorganite (15 and 30% v/v) and packed into the soil column at an average bulk density of 1.1 g/cm^3. Water was slowly added to soil columns until the soil become fully saturated. In addition, columns filled with water only were used to measure potential evaporation rates from the free water surface. The

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Table 1. Selected properties of milorganite and Krome soil used in the study

Properties	Krome soil	Milorganite
pH	7.6	6.2
EC (dS/m)	0.001	5.9
Total nitrogen (%)	0.09	4%
Organic carbon (%)	2.9	35.5
Total ash (%)	—	27.4

experiment was replicated three times and continued until daily evaporation rates from soil columns were relatively negligible.

Data collection

Daily evaporation rates were recorded by measuring weight losses using a digital scale. Electrical conductivity measurements were conducted, after extraction of samples with demineralized water (w/v = 1:5), using HANNA Benchtop probe (HI5522-01; Hanna Instruments Inc., Smithfield, VA, USA). The swelling property of milorganite was calculated after full saturation of samples for 24 h and subsequently allowing free draining of gravitational water until the field capacity was reached. After drainage stops, the difference between the initial volume and the volume at the field capacity was regarded as the swelling capacity of milorganite.

Soil moisture characteristics and hydraulic conductivity

Soil hydraulic properties were measured using the HYPROP and WP4C equipment (METER Group, Inc., Pullman, WA, USA). Air-dried soil samples were uniformly packed in stainless-steel cylinders. After packing, any excess soil at the top was carefully removed with a saw blade and the top was left open. Sample preparation and processing were done following a similar approach by Lipovetsky et al. (2020). Finally, the Hyprop-FIT software was used to develop soil moisture characteristics and hydraulic conductivity curves (Pertassek et al., 2015).

Statistical analysis

The R statistical programming software was used for data analysis, and analysis of variance tests were performed using the Kruskal–Wallis rank-sum test. The significant effect of milorganite application rate was tested at a 5% significance level ($p < .05$).

Results and discussion

Evaporation rates

Daily evaporation rates from all soil columns followed a similar trend to the potential evaporation (ET_o) rate from a free water surface at the beginning of the experiment (Figure 2a). However, evaporation rates from soils amended with milorganite sharply dropped after a week. There was an approximately 2–3-day lag in evaporation decline between the 15 and 30% milorganite treatments. On the other hand, evaporation rates from the control soil followed the rate from free water surfaces for a longer time. Comparing the ratios of soil evaporation with potential evaporation, as shown in Figure 2b, milorganite treatment reduced the length of Stage-I evaporation by more than half, leading to an extended period for Stage-II evaporation compared with non-amended control soils.

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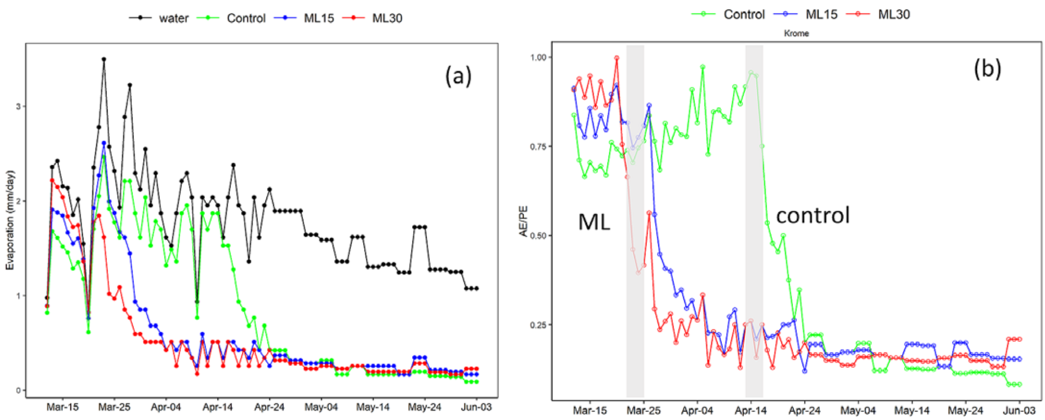

Figure 2. Daily evaporation rates from soils with and without milorganite and free water surface (a) and relative evaporation rates from soils compared with potential evaporation from a free water surface (b). The gray-shaded bars represent changes of evaporation from Stage I to Stage II for soils with milorganite and non-amended control soils.

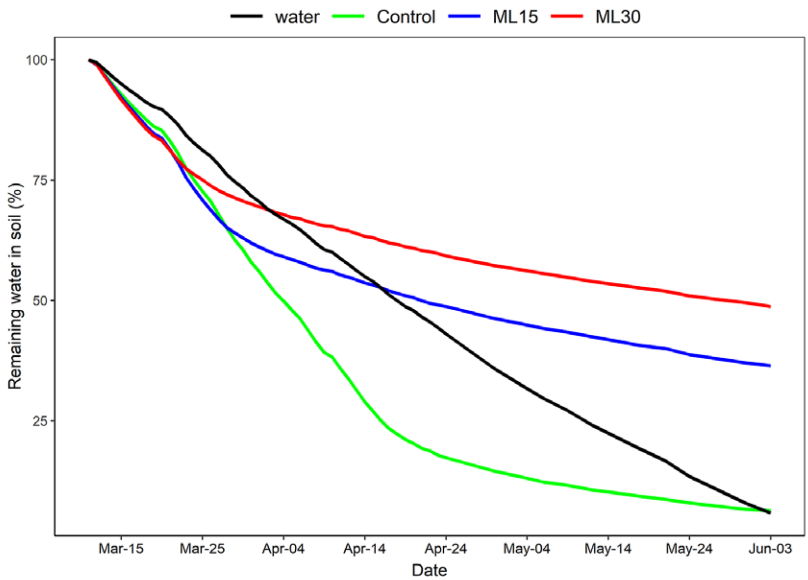

Figure 3. Percentage of water retention of soils with and without milorganite, and water columns. Treatment values are averages of three replications.

At the end of the experiment, milorganite amended soils retained about half of the water that was initially added compared to the non-amended control soil (Figure 3). There was a 10% difference in final moisture retained between the two milorganite rates (15 and 30%). Wang et al. (2020) and Avery et al. (2018) reported similar findings that milorganite increased soil-water retention. The reduction in the level of water in columns filled with water was linear, reaching near zero at the end of the experiment. It was apparent from this study that milorganite reduced evaporation rates while increasing moisture retention for extended periods, which suggests that milorganite could be used as a water conservation strategy in addition to being a source of nitrogen and phosphorous to plants.

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Soil moisture characteristics and hydraulic conductivity

Soil moisture characteristic curves of soils amended with milorganite showed a shift with higher moisture retention both near saturation and in the dry regions (Figure 4).

In most cases, milorganite amended soils had higher moisture content at a given pressure level. This could be due to increased absorption and retention of water by milorganite particles (Figure 4a). Results showed that the high moisture retention capacity of milorganite is associated with its high swelling capacity (Figure 5). The volume of a dry milorganite has increased by 54% at the field capacity, indicating the capacity of milorganite to absorb and retain water very well. A sharp decline in the moisture release curve was observed for the control soil. On the other hand, the soil hydraulic conductivity of milorganite amended soils was reduced by a factor of 200 compared with the control (Figure 4b). Hydraulic conductivity from 30% milorganite treatment showed a sharp decline with a small increase in pressure. This suggests that the swelling property of milorganite leads to the disruption of pore connectivity of soils, which limits the transportation of moisture from subsurface soil to surface soil, hence reducing the evaporation and hydraulic conductivity of soils.

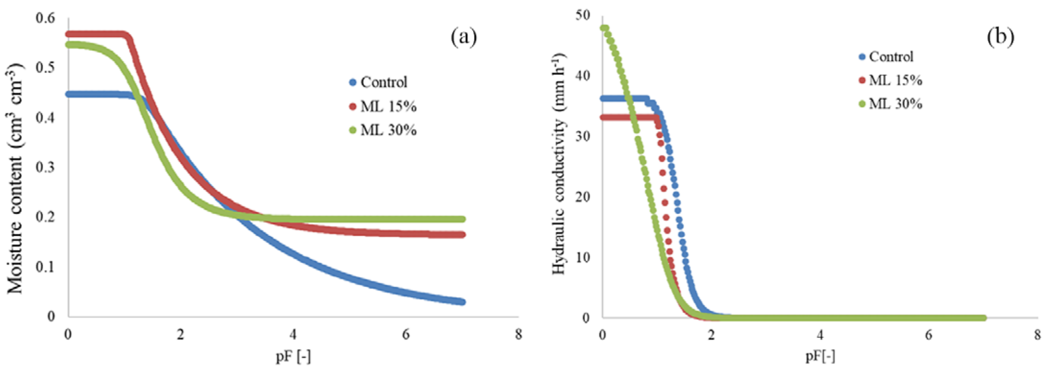

Figure 4. Soil moisture characteristic curves (a) and hydraulic conductivity (b) from control and milorganite treated soils. Note: hydraulic conductivity readings of 15 and 30% milorganite treatments were multiplied by 200 to achieve the same scale as the control for plotting.

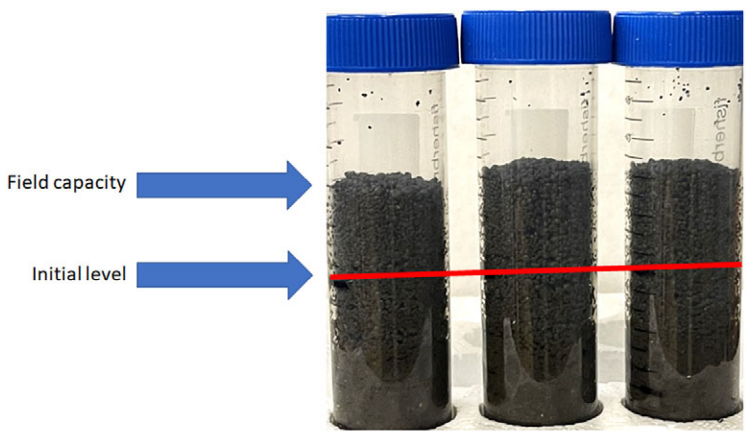

Figure 5. Swelling capacity of milorganite with the addition of water.

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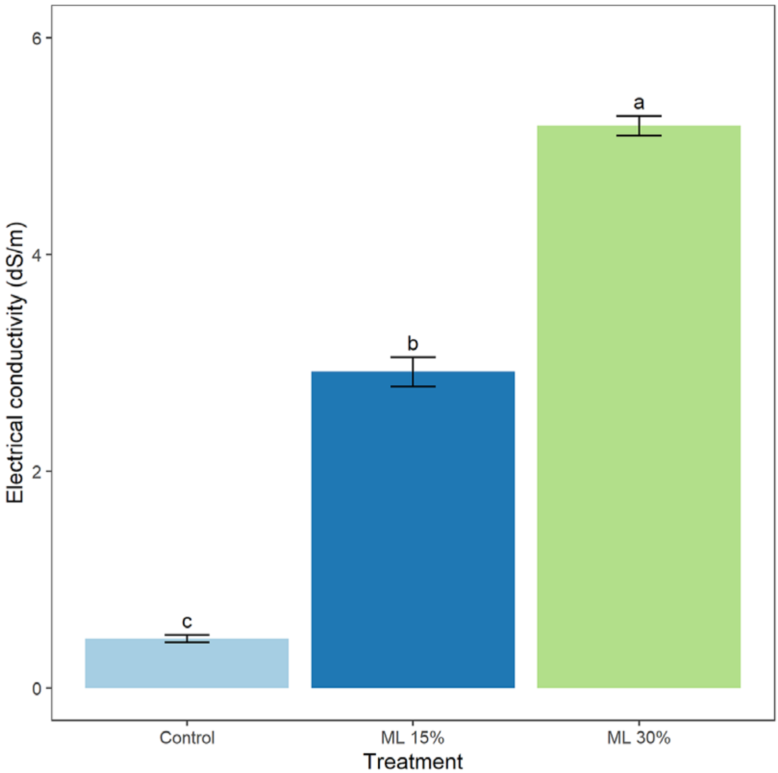

Figure 6. Effect of Milorganite on the electrical conductivity of the soil.

Electrical conductivity

The finding from this study demonstrated a significant increment of electrical conductivity of soil after the addition of both 15 and 30% of milorganite (Figure 6). The electrical conductivity of 30% milorganite addition was also significantly more than that of 15% milorganite treatment. The increment of soil electrical conductivity after the addition of the milorganite is clearly due to the much higher salt content of milorganite compared to the soil used in this study (Table 1). Studies show that salt accumulation in soil negatively affects plants by making soil water less available for plant use regardless of soil moisture status. At high salt levels, the osmotic potential of soil water increases (Sheldon et al., 2017). The increase in the electrical conductivity could put much pressure on plants. This is in agreement with the finding of Romero-Aranda et al. (2001), where it is reported that tomato yield and water uptake were reduced due to the increment in the salinity of the soil.

Conclusion

A study was conducted to investigate changes in evaporation and soil moisture characteristics of Krome soil with two rates of milorganite amendment. Milorganite amended soils had reduced evaporation rates compared with the control. Milorganite amendment reduced the length of Stage-I evaporation process, leading to an extended Stage-II evaporation period. This resulted in increased moisture retention and decreased hydraulic conductivity rates. The reduction of evaporation rates and hydraulic conductivity also suggests that milorganite incorporation leads to the disruption of the pore networks that are needed to transport water from subsurface depths. However, the effects of milorganite on salinity suggest that the increased moisture retention is less likely to be available for plant use as plants will have difficulty

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extracting water from soil with elevated salt levels. Therefore, the findings from our study suggest that irrigation management of milorganite amended soils should be optimized to avoid salt and water stress of plants grown on milorganite amended soil.

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Open peer review. To view the open peer review materials for this article, please visit http://doi.org/10.1017/exp.2022.25.

Data availability statement. The data used in this study are available upon request to the corresponding author.

Authorship contributions. H.K.B. conceived and designed the experiment. F.T.T., J.Z., and N.S.H. implemented the experiment and collected data. H.K.B. led the writing of the article with contributions from all the authors.

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Conflict of interest. The authors have no conflicts of interest to declare.

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Peer Reviews

Reviewing editor: Dr. Bartosz Adamczyk
Natural Resources Institute Finland, Viikki, Helsinki, Finland, 00790

Minor revisions requested.

doi:10.1017/exp.2022.25.pr1

Review 1: Changes in Soil Hydrological Properties Due to Organic Amendment

Reviewer: Dr. Shugang Zhang
Shandong Agricultural University, Tai'an, China, 271018

Date of review: 22 September 2022

Conflict of interest statement. Reviewer declares none.

Comment

Comments to the Author: This paper is well revised following my suggestions， so it is acceptable to be published now。

Score Card

Presentation

4.6 /5

Is the article written in clear and proper English? (30%)	5/5
Is the data presented in the most useful manner? (40%)	4/5
Does the paper cite relevant and related articles appropriately? (30%)	5/5

Context

4.8 /5

Does the title suitably represent the article? (25%)	5/5
Does the abstract correctly embody the content of the article? (25%)	4/5
Does the introduction give appropriate context? (25%)	5/5
Is the objective of the experiment clearly defined? (25%)	5/5

Analysis

4.6 /5

Does the discussion adequately interpret the results presented? (40%)	4/5
Is the conclusion consistent with the results and discussion? (40%)	5/5
Are the limitations of the experiment as well as the contributions of the experiment clearly outlined? (20%)	5/5

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Review 2: Changes in Soil Hydrological Properties Due to Organic Amendment

Reviewer: Dr. Adil Al-Salman

Date of review: 28 October 2022

Conflict of interest statement. I confirm that I have no conflicts of interest to declare.

Comment

Comments to the Author: The authors investigated the response of soil hydraulic properties to different amendment levels. However, there are many shortcomings in the work. The authors are encouraged to invest more time in revising the article and submitting it again.

1. The title. It's better to use hydraulic properties.

2. The abstract is poorly written. Rewrite to avoid repeating the same phrases many times and to correct the mistakes.

Line 20 “four replicates,” while "three replicates" in lines 84 and 139.

Line 21: Do the treatments also affect evaporation from the free water surface?! Rephrases needed.

3. The methodology. A lot of information was missed.

Line 81: Verify the EC number and unit by comparing it to fig. 6.

The authors didn't present the soil bulk densities for their packed treatments, which significantly influenced their results due to different initial volumetric water content. This is particularly important with the high swelling capacity of the used material. This applies to the evaporation and the HYPROP experiments.

4. The results. Line 144, fig 4 a. These are the fitted curves. You have to present the observed data for the HYPROP. Moreover, the curves have been extended beyond the measurement range of the HYPROP. I assumed they used the WP4C device to extend the curves, but they didn't mention that in the methodologies, and if they did, they should correct the measurement to subtract the osmotic pressure from the WP4C measurement, particularly with saline materials. Explain everything in the methodology and the results.

Line 145 saturated??.

Score Card

Presentation

3.3 /5

Is the article written in clear and proper English? (30%)	4/5
Is the data presented in the most useful manner? (40%)	3/5
Does the paper cite relevant and related articles appropriately? (30%)	3/5

Context

3.5 /5

Does the title suitably represent the article? (25%)	4/5
Does the abstract correctly embody the content of the article? (25%)	3/5
Does the introduction give appropriate context? (25%)	3/5
Is the objective of the experiment clearly defined? (25%)	4/5

Analysis

2.8 /5

Does the discussion adequately interpret the results presented? (40%)	3/5
Is the conclusion consistent with the results and discussion? (40%)	3/5
Are the limitations of the experiment as well as the contributions of the experiment clearly outlined? (20%)	2/5

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