Impact of Hydrochar Amendment on the Water Retention Capability of Agricultural Soil

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ABSTRACT

The water retention capability of soil significantly impacts plant growth. A scarcity of water in agricultural soil may cause low crop productivity, potentially leading to critical food-deficit problems in arid areas with increasing populations such as central California. New ways to enhance the water retention capability of soil to enable farmers to utilize water more effectively are thus urgently needed. Research has shown that hydrochar, which is produced by hydrothermal carbonization (HTC), can potentially improve soil quality by enabling it to hold water for longer periods. This study therefore explored how the addition of hydrochar affects water retention capacity in the root zone using soil experiments. For the experiments, a column filled with sample sandy soil but without hydrochar, which was used as a control. Meanwhile, 8% weight of hydrochar were mixed with soil at the top of soil columns to investigate how the presence or absence of hydrochar affected: (1) the temporal variation of soil moisture vs depth; (2) the temporal variation in the water's potential head vs. depth at different times; and (3) the distribution of soil moisture vs the water's potential head. The results of these experiments can be utilized to show the agricultural benefit gained by soil amendment with a certain amount of hydrochar.

INTRODUCTION

Agricultural areas around the world are experiencing serious problem due to soil contamination, the abuse of pesticides, and the use of nonrenewable energy. In order to deal with the predictable adverse consequences of climate change and the deteriorating soil conditions, new solutions for recycling and finding new uses for the large amount of bio-waste being generated are also urgently needed. The scarcity of water in agricultural soil is adversely affecting productivity in many areas, potentially leading to food-deficits in areas with rapidly growing populations. This problem is especially critical in arid areas such as central California. We urgently need to find new ways to enhance the water retention capability of soil to utilize precious water supplies more effectively. It has been suggested that hydrochar, a byproduct of hydrothermal carbonization, can be used to improve soil quality, allowing it to hold water for longer periods (Román et al. 2018). There is a growing awareness that this biomaterial, which was previously thought to be of little value, can be utilized by farmers to amend and improve the health, and hence the productivity, of their soil.

Two char by-products, biochar and hydrochar, both of which are by-products of emergent technologies for the management of waste biomass, can potentially play a huge role in alleviating soil problems. However, reports in the literature suggest that compared to conventional biochar, hydrochar is preferable for this type of application as the method used for its production endows it with uniquely beneficial characteristics, namely rich functional groups, temperate carbonization degree, and low acidity and porosity (Zhang et al. 2019). This type of char by-product is derived from wet biomass by hydrothermal carbonization, with the selected biomaterials being heated to between 150°C to 300°C in the presence of water under high pressure (Libra et al. 2011). This process can potentially transform contaminated biomaterials into resources in an efficient and sustainable method to create products that can be used to improve the level of soil carbon sequestration. Incorporating hydrochar improves the soil properties by boosting its carbon content and improving the soil structure and moisture retention capability (Beesley et al. 2011). There is thus the potential for significant growth in the use of these bio-products for agricultural applications in the next few years.

While there has been extensive research on the effect of incorporating biochar and hydrochar on the chemical properties of soils (Abel et al. 2013; Román et al. 2018), the effect of hydrochar on soil hydrologic characteristics remains largely unexplored. It is essential to determine how adding hydrochar affects the water retention capacity in the root zone. In the field, it is difficult to explore the movement of water under different meteorological conditions, but good results have been obtained using computational simulations (Wu et al. 1999). Simulating water and movement in infiltration irrigation using the hydrus-1d model (Simunek et al. 2005) is a useful way to explore how the soil characteristics change as a result of amending the soil with hydrochar. This model has proved to be an effective tool for simulating the movement of water in arid areas, achieving a simulation accuracy that was sufficiently high to be of use for practical agricultural applications (Zheng et al. 2017). In field experiments, soil columns have been used for a number of years to study hydrogeological properties and they can also be used to evaluate the performance of transport models designed to monitor the water retention distribution in the root zone of crops (Bruun et al. 2014).

The study reported here examined how the addition of hydrochar affects water retention capacity in the root zone using a combination of experiments and mathematical modeling. The effects of hydrochar on water retention and the potential for improving sandy soils were explored in laboratory tests.

MATERIALS AND METHODS

In this research, data was collected from soil experiments to determine the actual capacity and water retention distribution in the root zone of agricultural soil. In order to show how the addition of hydrochar affects water retention capacity in the root zone, the sample soil mixed with or without hydrochar was added in the soil columns separately.

A vertical 60 cm long transparent acrylic column with an inside diameter of 7.5 cm and an outside diameter of 8.5 cm. was utilized for the soil experiment to test the soil's actual and potential water retention capacity (Figure 1). To investigate the water retention ability under different irrigation conditions, the first 30 cm of the column was filled with soil and the remainder of the column connected to an irrigation device. Twelve apertures distributed along the left side of the column were fitted with TEROS 10 and TEROS 11 soil moisture sensors (Meter Group Inc., Pullman, WA) to measure the water content. These sensors are appropriate for experiments that examine temporal variation over long periods of time (Sathian and Narayanan 2021). Water potential sensors (TEROS 31 Tensiometers, Meter Group Inc.) were installed in 11 holes distributed along the right side of the column. These sensors are sufficiently small to deliver accurate spot measurements through the column measuring holes. All the sensors were connected to ZL6 Data Logger (Meter Group Inc.), which sent the data collected to the cloud. To maintain a constant water flow rate above the soil surface, a Mariotte Bottle was installed at the top of the soil column to simulate a normal irrigation situation.

For the soil experiment, the sample soil used was a mixture of dried sand and top soil. The soil particle size distribution and the bulk density were measured before the soil experiment commenced. The sample soil was assumed to have the characteristics of sandy soil. The air-dried sample soil, whose initial soil water content was measured, was passed through a 2 mm screen before being loaded into the column. Sample soils were loaded every 10 cm into the column, totally three times. The porosity of the sample soil was 39.21%. The hydrochar used here was produced from food waste (Idowu et al. 2017) kindly provided by the University of South Carolina Laboratory. Several additional soil columns were constructed using the above method. As well as a column filled with sample sandy soil but without hydrochar, which was used as a control, another column was filled with the same sample sandy soil as the first column, but with hydrochar in the top layer alone (Figure 2) while another had 8% weight percent of hydrochar mixed uniformly throughout the soil. The porosity of soil and hydrochar mixture was 42%.

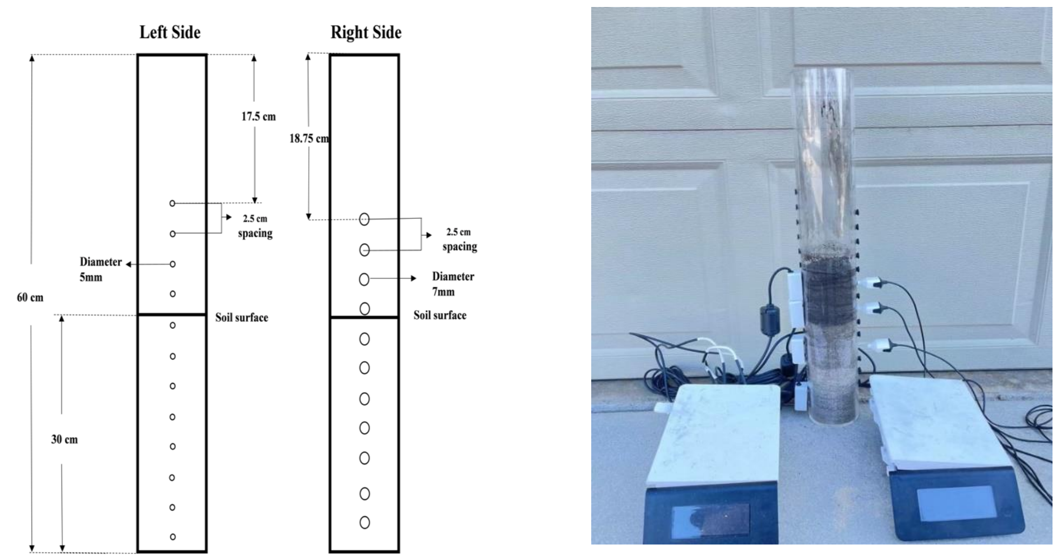

Figure 1. Schematic representation of experimental soil column

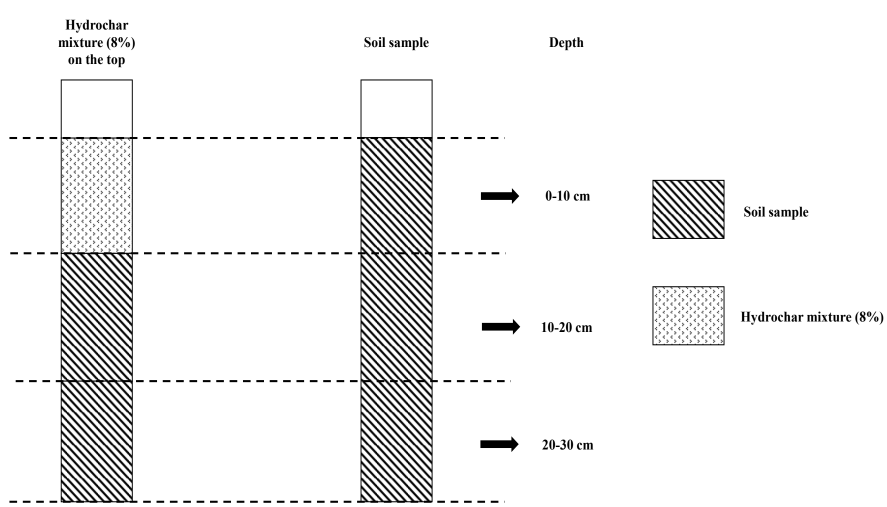

Figure 2. Diagram for soil columns set up with/without hydrochar

RESULTS AND DISCUSSION

Analysis of experimental data

The temporal variation of soil water content measured at different depths is shown in Figure 3. The results were obtained across the entire 30 cm length of the soil column when four moisture sensors were inserted. 250 ml of water were added before the water content was measured at the same time with hydrochar provided in Figure 3(a). The control soil experiment was conducted with no hydrochar in Figure 3(b). Here, the soil moisture increased rapidly initially, approaching a stable value after just 1 hour. Comparing these two figures above, the soil moisture was very low at a depth of 19 cm and almost dry at a depth of 26.5 cm. It presents that the water content of the sample soils without hydrochar were both less than 0.25 m^3/m^3 provided in Figure 3(c). These results clearly show the highest soil water content was found in the soils containing hydrochar. The reason is because of the higher water retention capacity of hydrochar which has smaller pores.

To verify the water retention capacity of hydrochar, different amount of water was added into the column. After adding 850 ml of water, the soil mixture in the whole soil column was under saturated condition without any clogging. The results are shown in Figure 4. The soil water content increased rapidly at the first hour, approaching a stable value. Soil moisture at 3.5 cm reached maximum at first. But because of the huge amount of water, water flowed down and was hold at 9 cm of the first layer of the column. The soil moisture at mixture layer is almost higher than the layers below. But the reason why soil water content at bottom is higher than the middle is the huge water quantity and higher permeability of sand soil, water flowed and deposited at the bottom after two hours. This experiment led to very similar results with that of 250 ml of water, which may further indicate the promising water retention capability of the hydrochar.

In the following section, we present soil water potential head at different depths of a soil column when the sensors were left in place for 24 hours. The results are shown in Figure 5. The temporal variation in the water potential with 8% hydrochar provided in Figure 5(a). At the middle and bottom of the column, no water flowed into these layers because of the strong water-holding capability of hydrochar. The results of the controlled experiment without hydrochar is shown in Figure 5(b). Here, the soil water potential increased rapidly initially and was close to zero in just 1 hour. This indicates that the sample soil had almost achieved saturation after adding 250 ml water at the beginning of the hour. However, Figure 5(c) shows the water potential was not uniform across the sample for the first 30 min. The measurements obtained for the sample soil without hydrochar were both less than were predicted by the model. This is likely because adding hydrochar significantly improved the soil's water retention capability.

The relationship between moisture and the matric potential in the top layer of the 30 cm column is shown in Figure 6. The soil mixed with hydrochar exhibited the greatest potential when the water content was uniform across the various depths. Here, the error bars represent the standard error. Examining the figure, the slope of the soil with hydrochar is clearly higher than that of the sample soil. This provides strong evidence that hydrochar can indeed enhance the water retention capability of soil to utilize water more effectively in the soil.

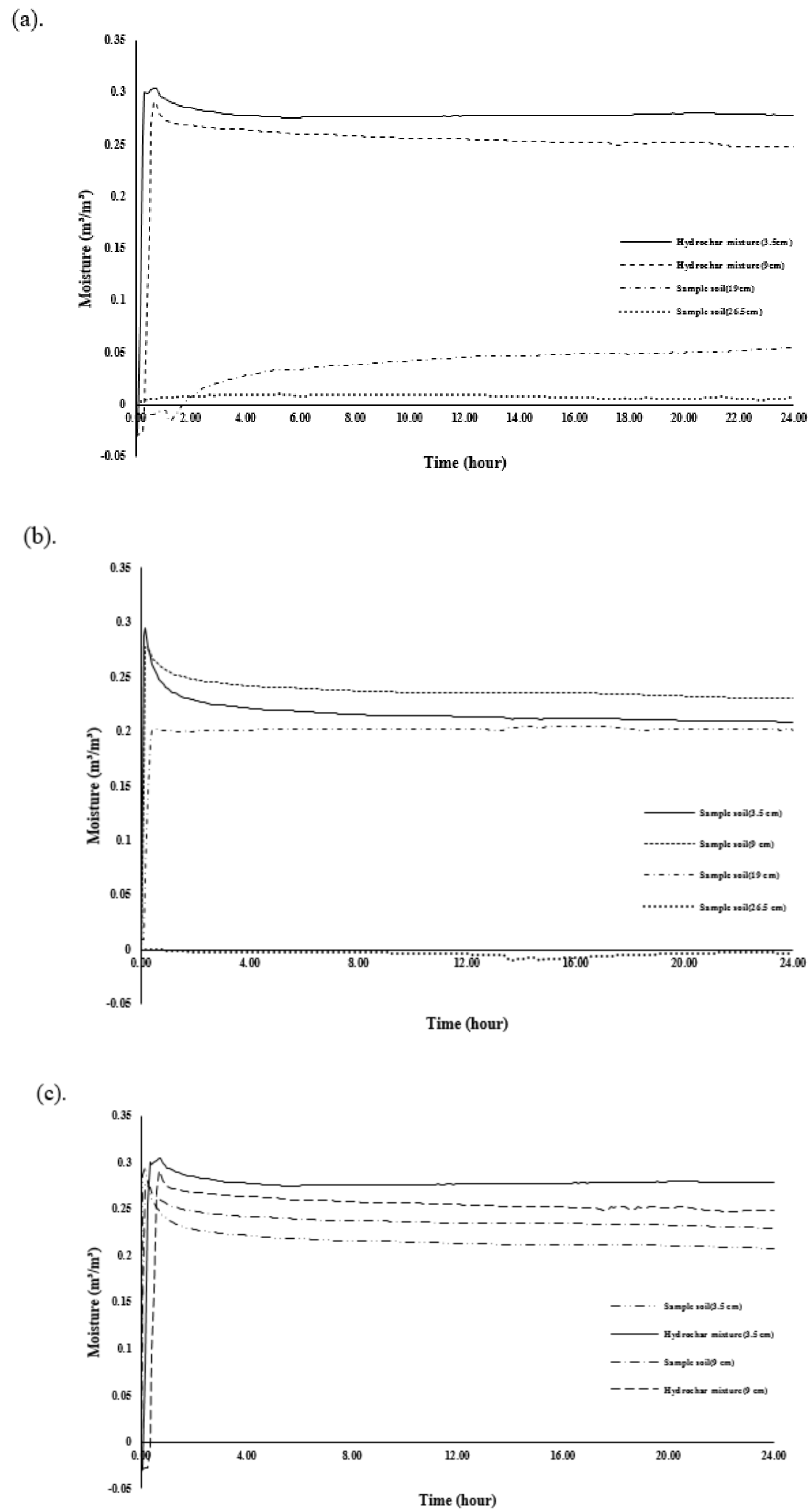

Figure 3. Temporal variation of soil moisture at different depths: (a). 8% hydrochar; (b). without hydrochar; (c). comparison at depths between 3.5 cm and 9 cm with hydrochar

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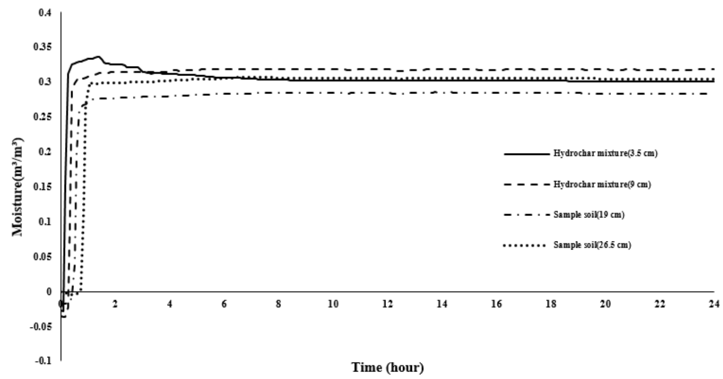

Figure 4. Temporal variation of soil moisture at different depths adding 850 ml of water with 8% hydrochar

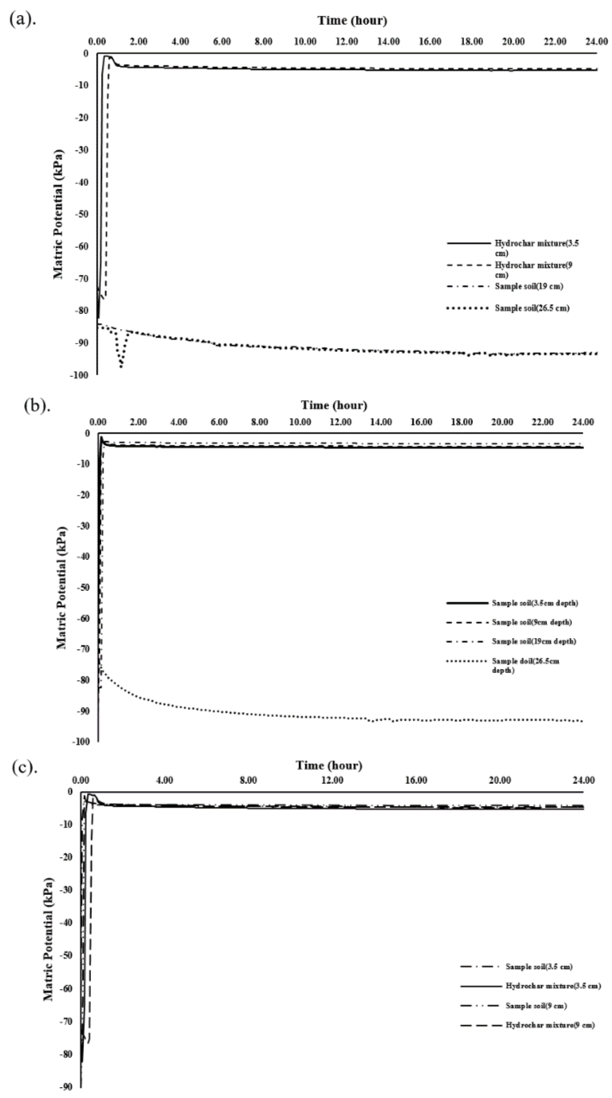

Figure 5. Temporal variation of water potential head at different depths: (a). 8% hydrochar; (b). without hydrochar; (c). comparison at depths between 3.5 cm and 9 cm

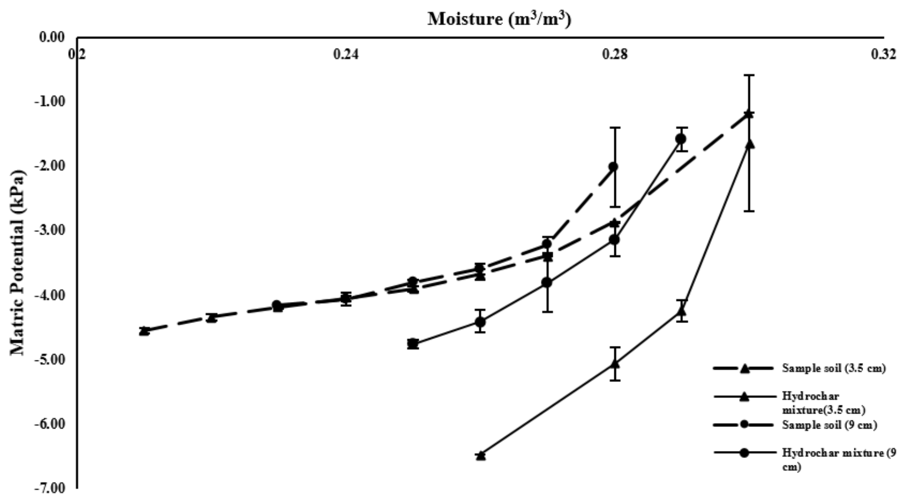

Figure 6. Soil water content vs. water potential at depths of 3.5 cm and 9 cm with 8% hydrochar

The data collected in the experiments conducted for this research also show that the wetting front arrived relatively slowly at the interfaces between the 10 cm soil layers and this changed with time. The wetting front initially showed a downward trend before finally reaching a balance. Moreover, the velocity of the moving wetting front changed significantly at the top, middle, and bottom interfaces in the soil column. The velocity at which the water moved through the layers containing hydrochar was obviously slower than in layers composed of the sample soil alone. This variation is likely because of the different water retention capacities of the layers with and without hydrochar, which affects the structure of the soil mixtures.

The temporal variation in the water content and potential head without hydrochar but with the free drainage as the bottom boundary condition and a 3 cm-constant water head above the soil surface over a period of 12 hours is provided in Figure 6. For these measurements, the sensors were installed at the top layer of the column. As the potential increased, the moisture increased rapidly, approaching 0.37 m^3/m^3 after 1 hour's infiltration, which is close to saturation.

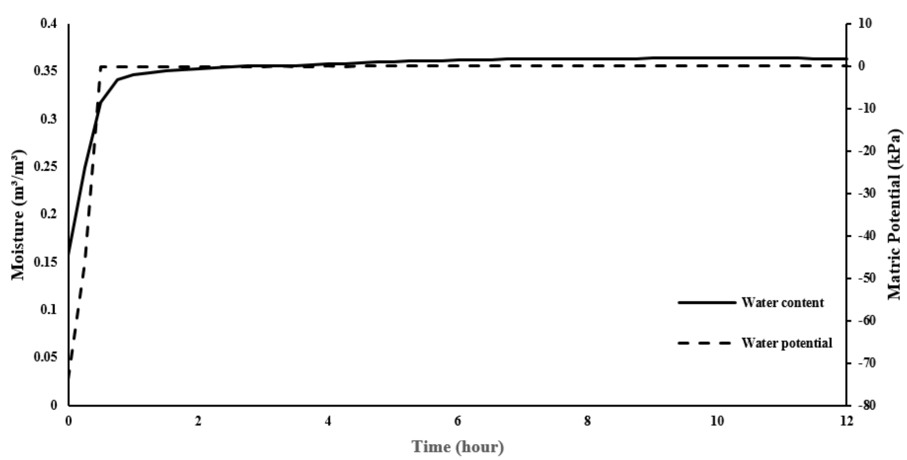

Figure 7. Free drainage soil experiments showing the temporal variation in the water content and potential head

This study has demonstrated that hydrochar from food waste has significant potential as an amendment treatment to improve soil quality, especially in sandy soil. However, further research is needed to determine the most appropriate levels that maximize the benefits for crop growth. Research is also needed to examine any long-term effects of incorporating hydrochar into soil.

CONCLUSIONS

The addition of food waste-hydrochar as an amendment to agricultural soil boosts the soil moisture levels and increases its water retention capability. This finding was confirmed by soil experiments, which clearly showed the improved water retention achieved in amended sandy soils. Overall, the results of this study provide essential step that will contribute to the ongoing effort to develop hydrochar technology as a way to produce a useful and effective amendment for agricultural soil.

REFERENCES

Abel, S., Peters, A., Trinks, S., Schonsky, H., Facklam, M., and Wessolek, G. (2013). “Impact of biochar and hydrochar addition on water retention and water repellency of sandy soil.” *Geoderma*, 202-203, 183-191.

Beesley, L., Moreno-Jiménez, E., Gomez-Eyles, J. L., Harris, E., Robinson, B., and Sizmur, T. (2011). “A review of biochars’ potential role in the remediation, revegetation and restoration of contaminated soils.” *Environmental pollution*, 159(12), 3269-3282.

Bruun, E. W., Petersen, C. T., Hansen, E., Holm, J. K., and Hauggaard-Nielsen, H. (2014). “Biochar amendment to coarse sandy subsoil improves root growth and increases water retention.” *Soil Use and Management*, 30(1), 109-118.

Idowu, I., Li, L., Flora, J. R. V., Pellechia, P. J., Darko, S. A., Ro, K. S., and Berge, N. D. (2017). “Hydrothermal carbonization of food waste for nutrient recovery and reuse.” *Waste Manag*, 69, 480-491.

Libra, J. A., Ro, K. S., Kammann, C., Funke, A., Berge, N. D., Neubauer, Y., Titirici, M.-M., Fühner, C., Bens, O., and Kern, J. (2011). “Hydrothermal carbonization of biomass residuals: a comparative review of the chemistry, processes and applications of wet and dry pyrolysis.” *Biofuels*, 2(1), 71-106.

Román, S., Libra, J., Berge, N., Sabio, E., Ro, K., Li, L., Ledesma, B., Álvarez, A., and Bae, S. (2018). “Hydrothermal Carbonization: Modeling, Final Properties Design and Applications: A Review.” *Energies*, 11(1).

Sathian, K. K., and Narayanan, J. (2021). “Laboratory Calibration of Capacitance-Based Soil Moisture Sensor to Monitor Subsurface Soil Moisture Movement in Laterite Soil.” *International Journal of Plant & Soil Science*, 137-147.

Simunek, J., Sejna, M., Saito, H., Sakai, M., and Van Genuchten, M. T. (2005). “The HYDRUS-1D Software Package for Simulating the One-Dimensional Movement of Water.” Heat, and Multiple Solutes in Variably-Saturated Media, Version, 3.

Wu, J., Zhang, R., and Gui, S. (1999). “Modeling soil water movement with water uptake by roots.” *Plant and soil*, 215(1), 7-17.

Zhang, S., Zhu, X., Zhou, S., Shang, H., Luo, J., and Tsang, D. C. (2019). "Hydrothermal carbonization for hydrochar production and its application." *Biochar from Biomass and Waste*, Elsevier, 275-294.

Zheng, C., Lu, Y., Guo, X., Li, H., Sai, J., and Liu, X. (2017). "Application of HYDRUS-1D model for research on irrigation infiltration characteristics in arid oasis of northwest China." *Environmental Earth Sciences*, 76(23), 785.