# Exploring Efficiency of Biochar in Enhancing Water Retention in Soils with Varying Grain Size Distributions using ANN Technique

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# Abstract

Recently, incentives have been provided in many countries, including Canada and Denmark, to produce biochar for construction usage. This is done because biochar is carbon negative and can help achieve the emission reduction goal of 2030. This technical note aims to analyze the efficiency of biochar in soils with varying grain size distribution for enhancing water retention capacity (WRC). The combinations of biochar content and grain size distributions corresponding to the maximum and minimum efficiency were explored. Artificial Neural Network (ANN) based model for predicting Soil Water Characteristic Curve (SWCC) as a function of soil suction and grain size distribution was developed. A new factor (the ratio of fine (silt + clay) and coarse (sand) content) was proposed for the interpretation of the efficiency of biochar in soils. The newly developed model is able to predict SWCC reasonably well. Biochar amendment is found to influence both dry and wet sides of soils with a clay content lower than threshold content (6–8%). Beyond threshold content, the influence of biochar appears to reduce. However, in the case of high sand content soils (90%), the NWC value on the drier side is generally higher as compared to soils with lower sand content. Based on sensitivity analysis, it was found that the ratio of fine to sand content is the most influential, while biochar content is the least influential.


# Declarations


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**Availability of data and material:** Data used to support the findings of this study are available from the corresponding author upon request.

# List Of Abbreviations

| | |
|---|---|
| ANN | Artificial Neural Network |
| BAS | Biochar Amended Soils |
| MAPD | Mean Absolute Percentage Deviation |
| NWC | Normalized Water Content |
| PAW | Plant Available Water |
| PWP | Permanent Wilting Point |
| $R^2$ | Coefficient of Determination |

| | |
|---|---|
| SWCC | Soil Water Characteristic Curve |
| WHC | Water Holding Capacity |
| WRC | Water Retention Capacity |

# Introduction

The biochar addition generally increases the Water Retention Capacity (WRC) of soils, which can be attributed to the biochar's high porosity and hydrophilic nature [1–3]. In addition, biochar has many other promising properties like carbon sequestration, high plant nutrient value etc. [4–13]. This enhancement mainly depends on the type of the feedstock of biochar, the type of soil, and the soil biochar mixture rates. It is necessary to understand the water retention mechanism of Biochar Amended Soils (BAS) to promote biochar as a soil amendment [14]. Sufficient literature is available, which shows that the water holding capacity (WHC) of the biochar soil composite is increased compared to bare soil [15, 16]. Mollinedo et al. (2015) [17] observed that the fine-sized biochar particles change the soil pore arrangement, increase surface area, void ratio and WHC of soil biochar composite. On applying biochar to soil, the WHC of soil (medium textured boreal agriculture soil) increased by 11% [18] and 32% [19] in sandy loam soil. Gopal et al. (2019) [20] observed a reduction in infiltration rate and an enhancement in WHC with an increase in biochar amendment. Similarly, Garg et al. (2020) [21] observed that the addition of biochar increased the WRC of unsaturated soils (loam and sandy loam). The study also demonstrated that the addition of biochar modified soil water retention capacity (SWRC).

Porosity, void ratio and soil structure get altered by biochar addition, specifically depending upon the particle shape, size, and internal structure of biochar [22]. The internal structure of biochar particles determines their WHC, shape (elongated/oval/spherical), and size determines the complexity and density of soil-biochar composite and capillary system [23]. Liu et al. (2017) observed the effect of 2% biochar amendment of three different particle size samples with sand. It was noticed that the saturation water content, field capacity, permanent wilting point (PWP), and plant available water (PAW) in SWRC increased when compared with the other two samples; sand – fine sand and sand + coarse sand (replacing biochar with fine sand and coarse sand). The authors concluded that more porous and irregular shaped biochar particles are more effective in increasing water retention of sandy soils [23–26]. Duarte et al.(2019) [27] modified eight samples with agricultural residue biochar of size > 2mm, 2 – 0.15 mm and < 0.15 mm with 200 g soils (loamy and sandy) at 0.92 g of biochar (~ 25 Mg/hec). After allowing an incubation period of one year, it was noticed that biochar particle size of < 0.15 mm is most suitable for increasing water retention in the soils (particularly loamy soil). It was observed that soil's physical properties were dependent upon the particle size of biochar. Similarly, in another study conducted by Alghamdi et al. (2020) [28], fine biochar particles < 0.1 mm increased the water content at field capacity and available water content more than that of particle size greater than 0.1 mm, probably due to increased surface area, microporosity and biochar's porous structure in light-textured soils after an incubation period of 120 days.

Though many studies reported an increase in WHC, there are some studies where effect of biochar has been either negligible or negative. Some authors observed both increase and decrease [29–32], some reported increase only [33], whereas some reported no effect [5]. Bordoloi et al. (2019) [34] observed an increase in WHC of silty sandy soil, while Hardie et al. (2014) [35] observed no noticeable effect of biochar on drainable porosity, field capacity, PWP, PAW content or soil moisture content of a sandy, loamy soil. Further, the effect of biochar on WHC may vary with the type of feedstock, from which biochar was produced [2, 36]. Biochars produced from plant feedstock types tend to have higher porosity than that of animal feedstock [36–38]. As far as authors are aware, there is a lack of systematic study that investigates the extent of biochar effect on WHC of soils with varying grain size distribution. It is difficult to interpret the extent or efficiency of biochar on WHC of soils from literature due to high variability in testing conditions such as instrumentation, climate and type of biochar.

Artificial Neural Network (ANN) has proved to be an alternative technique for analysing material behaviour from limited experimental results [1, 2, 39–41]. Many studies have reported using the ANN to study soil properties [42, 43]. ANNs are based on a learning technique that imitates the biological learning process occurring in the brain and presents a robust way to predict responses from a dataset [44, 45]. Vasu et al. (2016) [46] used ANN to estimate soil-water characteristic curve (SWCC) for Korea's weathered soil using Fredlund and Xing equation. Zainal and Fadhil (2018) [47] determined SWCC by ANN using properties like air entry point and residual degree of saturation. Similarly, Johari and Hooshmand (2015) [48] used gene expression programming to predict SWCC. Johari and Javadi (2011) [49] used clay and silt contents along with void ratio, gravitational water content and suction and estimated SWCC using the ANN technique. Hence, ANN technique can serve as an important tool for developing models and analysing soil behaviour.

This study aims to investigate the efficiency of biochar in affecting the WHC of soils with varying grain size distribution. Database of SWCCs of soils with and without biochar amendment was systematically established. ANN models were developed based on an established data set. Models were developed as a function of parameters such as percentages of biochar amendment, clay, sand and a new factor (the ratio of fine (silt +clay) and coarse (sand) content).

# Materials And Methodology

### 2.1 Test Procedure

Measured data was collected from the literature [12, 31, 50–53] are used in this study. Soils from these studies varied from sandy to silty clay and pure clay. Sand content, clay content and silt content vary from 58% – 98%, 0% – 20% and 2% – 37%, respectively. Biochar amendment varies from 0% to 15%. Biochars were obtained from different feedstocks types such as Water hyacinth, Peanut shell and Dairy Manure. Detail of biochar type and production was given in one of the studies [50]. The biomass had a lignocellulosic nature with 46% cellulose content and 21% hemicellulose. The procedure prescribed by Gogoi et al. (2017) [54] was adopted for the production of biochar. The biomass was cut into small pieces of 30 mm – 50 mm. The temperature of the pyrolysis process was maintained at 300°C - 500°C for 45 minutes as per the optimum conditions for water hyacinth species [55]. The biochar produced was cut using an automatic crusher and sieved through a 2 mm sieve. After achieving the desired torrefaction temperature required for biochar production, the sample was removed and subjected to further analysis. The procedure for establishing soil-water characteristic curve varies among the above studies. Studies [50–52] have established SWCCs using simultaneous measurements of volumetric water content and soil matric suction in a 1-D column set up, which contains compacted soil-biochar composite. Wong et al. (2016) [12] utilized the vapour equilibrium technique to measure SWCC of compacted kaolin clay amended with different biochar percentages.

For preparing the dataset for the training of models, the volumetric water content of the soils was normalized with their maximum water content (i.e., to establish Normalized water content (NWC). NWC is defined as per the following equation:

$$\text{Normalized Water Content} = \frac{\text{Volumetric Water Content}}{\text{Maximum Water Content}} \qquad (1)$$

This is done to minimize any fluctuations in the data caused due to variation in soil types, soil density, instrumentation type etc. Future studies need to be conducted to establish full-scale SWCCs for various soil types using the same set of instrumentation and testing conditions (i.e., soil density and soil type).

### 2.2 ANN Procedure

Artificial Neural Network (ANN) is a learning algorithm that implicitly describes the nonlinear and complex relationship between input data and output results [39, 56]. In the present study, the commercially available STATISTICA, version 12 software was used. To develop the model seven input parameters viz. soil suction, biochar content, sand content, silt content, clay content, fine content (silt and clay) and the ratio of fine content to sand content were used. Corresponding to these seven parameters, normalized water content was predicted using two hidden layers in the ANN architecture. Figure 1 presents a flowchart that shows a methodology used for the implementation and Figure 2 illustrates the three-layer ANN architecture.

## Results And Discussion

### 3.1 Comparison between measured and predicted results

The number of soil samples used in the study was 23. Corresponding to these samples, 794 data points were obtained from the literature. These data points were divided in the ratio of 80:20 for training and testing, respectively. Figure 3 shows a comparison is drawn between the measured and the predicted output. The SWCC is plotted between normalized water content and soil suction. The proposed model's coefficient of determination ($R^2$) and Mean Absolute Percentage Deviation (MAPD) calculations are conducted using the following equation:

$$MAPD = \frac{100}{n}\sum_{i=1}^{n}\frac{(M_i - P_i)}{M_i} \qquad (1)$$

Where $M_i$ = Measured Value, $P_i$ is the Predicted Value, and n is the number of observations.

The $R^2$ value was found to be 0.7109. It is observed that measured and predicted NWC follow a trend, indicating accuracy (in terms of $R^2$) of the prediction of NWC. The error percentage as calculated by MAPD was reported to be 13.76%.

In order to further visualize the predictive ability of the model, estimated SWCCs for three particular soils at different biochar contents of 0%, 5% and 10% were compared with the measured ones in figures 4 (a), (b) and (c), respectively. It should be noted that only a few selected plots have been used for comparison. This has been done based on the availability of complete data of grain size distribution and also reported SWCCs at different biochar contents (0%, 5% and 10%). For each measured SWCC, three predictions were made to analyse the influence of variation in individual silt, and clay contents as in literature, only total fine (silt and clay) content was available. It is evident from the figures that the results of water content obtained from measured and predicted SWCC's are comparable.

### 3.2 Influence of clay and silt content on SWCC of soils amended with biochar at different contents

Figures 5 (a) and (b) show the biochar effectiveness on SWCCs of soil with different silt and clay content. Analyses were conducted by keeping the ratio of fine to coarse content (0.667), fine (silt and clay of 40%) and sand content (60%) constant. Clay was varied from 0% to 10%. Correspondingly, silt varied from 40% to 30%. The influence of silt and clay content on SWCCs was analysed for two different biochar percentages (i.e., 3% and 10%), as shown in figures 5 (a) and (b), respectively.

As observed in figure 5 (a), NWC reduced from 0.9 to 0.65, with an increase in suction for clay contents up to 6%. NWC of 0.65 represents normalized water content corresponding to the drier part of the soil. However, for clay content of 6%, minimum NWC reduced further up to 0.35. At 6% clay content, the change in normalized water content at the wetter side of SWCC is still insignificant. This seems to suggest that with a constant biochar content of 3%, the efficiency (change) of biochar to affect SWCC seems to reduce with an increase in clay content at 6%. The possible reason could be that the amount of smaller size of pores is enhanced with an increase in clay content beyond this optimal amount. Any further addition of finer biochar may not be significant since the existing smaller pores of clay will instead engulf biochar particles. Such pore-filling mechanism effects have also been discussed in the literature (Duarte et al., 2019). For clay content above 8% or above, a significant reduction in NWC is also observed in the wetter side of SWCC. It suggests that for higher clay contents, any effect of biochar may not be significant on the drier or wetter side of SWCC.

The trend of SWCCs for soils at a biochar content of 10% appears to be similar to that of 3%. However, some changes are observed in SWCCs when biochar content is increased to 10%. The threshold clay content beyond which reduction in NWC takes place increased from 6% (biochar content of 3%) to 8%

(biochar content of 10%). It also suggests that at the threshold clay content is higher for soils with a larger amount of biochar. The implications of these results suggest that any addition of biochars may not be useful for soils with clay content higher than 6%. This conclusion is obviously dependent on the data used for training of model and prediction. However, this result suggests an important precaution for avoiding excessive use of biochar in soils with higher fine content.

In a similar manner, the effect of biochar is likely to be lower in soils compacted at higher densities. Compaction results in a reduction in average pore size. Garg et al. (2021) [52] also conducted series of experiments to determine the influence of biochar on water retention in soils compacted at different densities. It was found in their study that biochar was found to be more efficient in soil compacted at 65% followed by 80% compaction as compared to 95%. The pore-filling mechanism of biochar influences water holding capacity and hence, plant available water. The optimum biochar percentage addition makes a biochar soil composite with a higher hydraulic conductivity due to a large and continuous porous system [57]. 5% biochar addition showed more plant available water than 2.5% [58]. The review conducted by Edeh et al. (2020) [59] observed that the biochar amendment > 30 t/ha and < 30 t/ha were feasible for coarse and fine-grained soils, respectively.

### 3.3 Influence of biochar types on soil with higher sand content

Figures 6 shows the influence of biochar content on SWCCs of soil with higher sand content (i.e., 90%). It can be observed that with an increase in biochar content, there is a slight increase in NWC of soil at the wetter side of SWCC. On the other hand, the change in NWC on the drier side of SWCC is insignificant with an increase in biochar content (except for 10%). The observation is different from that of soils with a relatively higher ratio of fine to coarse content (refer to figures 4 (a) and (b)). It was found in figures 4 (a) and (b) that the influence of biochar is relatively more on the drier side of SWCC than on the wetter side. There was a threshold clay content, beyond which the effect of biochar was significant on the wet and dry side of SWCC. It was found in figure 6 that the presence of excessive biochar (i.e., 10%) can cause a reduction in NWC. This implies that for soil with very high sand content, there is a relatively high requirement of biochar content (at least 10%) for causing a significant change in NWC. Previous studies revealed the effects of biochar on hydraulic characteristics [32]. Biochar amendment increases the water retention capacity, which is also influenced by biochar feedstock, pyrolysis temperature, pyrolysis duration and soil types [30]. Arthur et al. (2015) [60] observed an increase in WHC due to biochar at a high suction range in non-compacted sandy loam soil.

It can be found from figure 7 that the ratio of fine to sand content is the most influential parameter affecting NWC (figure 7). The ratio of fine to sand content indirectly influences the microstructural arrangement and hence, water retention capacity. This is followed by sand content, silt content and soil suction. Interestingly, biochar content seems to be the least important parameter among all. The results seem to suggest that the ratio of fine to sand content is an important parameter while determining the efficiency of biochar. It should be noted that the conclusions are based on a limited set of data, and any influence of soil compaction and feedstock type of biochar is not taken into account.

## Conclusion

This study aims to analyse the efficiency of biochar on SWCC of soil with varying grain size distribution. A new factor (ratio of fine to sand content) was defined to understand the extent of influence of biochar on SWCC. The ANN-based model was found to predict SWCC reasonably well. Based on predictions, it was found that there is a threshold clay content (6% to 8%) beyond which any effect of biochar becomes less significant. However, for soils with higher sand content, there is a slight increase in normalized water content on the wetter side of SWCC with the presence of biochar. A relatively higher amount of biochar (i.e., 10%) is required for causing changes in the drier side of SWCC for sandy soils. Based on sensitivity analyses, the ratio of fine to sand content was also found to be the most important factor causing changes in NWC. This is because the ratio indirectly influences the microstructural arrangement and hence, soil water retention capacity.

In contrast, biochar content was found to be comparatively least influential. It should be noted that the above conclusions are based on the given set of measured data that was available in the literature. Further, there is also a lack of enough data of SWCC at the higher range of soil suction and also for various types of biochar produced from different feedstock types. More systematic studies need to be conducted to establish full-scale SWCC for soils amended with various types of biochars (i.e., animal-based and plant-based).

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## References

1. Garg A, Huang H, Kushvaha V, et al (2019) Mechanism of biochar soil pore–gas–water interaction: gas properties of biochar-amended sandy soil at different degrees of compaction using KNN modeling. Acta Geophys. https://doi.org/10.1007/s11600-019-00387-y

2. Wani I, Kumar H, Rangappa SM, et al (2021) Multiple Regression Model for Predicting Cracks in Soil Amended with Pig Manure Biochar and Wood Biochar. Journal of Hazardous, Toxic, and Radioactive Waste 25:04020061. https://doi.org/10.1061/(ASCE)HZ.2153-5515.0000561

3. Zhang Y, Gu K, Li J, et al (2020) Effect of biochar on desiccation cracking characteristics of clayey soils. Geoderma 364:114182. https://doi.org/10.1016/j.geoderma.2020.114182

4. Doan TT, Henry-des-Tureaux T, Rumpel C, et al (2015) Impact of compost, vermicompost and biochar on soil fertility, maize yield and soil erosion in Northern Vietnam: A three year mesocosm experiment. Science of The Total Environment 514:147–154. https://doi.org/10.1016/j.scitotenv.2015.02.005

5. Jeffery S, Meinders MBJ, Stoof CR, et al (2015) Biochar application does not improve the soil hydrological function of a sandy soil. Geoderma 251–252:47–54. https://doi.org/10.1016/j.geoderma.2015.03.022

6. Lehmann J, Joseph S (2015) Biochar for Environmental Management: Science, Technology and Implementation. Routledge

7. Ramola S, Kumar Srivastava R, Vasudevan P (2013) Effect of biochar application in combination with domestic wastewater on biomass yield of bioenergy plantations. International Journal of Energy Sector Management 7:355–363. https://doi.org/10.1108/IJESM-03-2013-0005

8. Ramola S, Mishra T, Rana G, Srivastava RK (2014) Characterization and pollutant removal efficiency of biochar derived from baggase, bamboo and tyre. Environ Monit Assess 186:9023–9039. https://doi.org/10.1007/s10661-014-4062-5

9. Reddy KR, Yaghoubi P, Yukselen-Aksoy Y (2015) Effects of biochar amendment on geotechnical properties of landfill cover soil. Waste Manag Res 33:524–532. https://doi.org/10.1177/0734242X15580192

10. Van Zwieten L, Kimber S, Morris S, et al (2010) Effects of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility. Plant Soil 327:235–246. https://doi.org/10.1007/s11104-009-0050-x

11. Wani I, Ramola S, Garg A, Kushvaha V (2021) Critical review of biochar applications in geoengineering infrastructure: moving beyond agricultural and environmental perspectives. Biomass Conv Bioref. https://doi.org/10.1007/s13399-021-01346-8

12. Wong JTF, Chen Z, Ng CWW, Wong MH (2016) Gas permeability of biochar-amended clay: potential alternative landfill final cover material. Environ Sci Pollut Res 23:7126–7131. https://doi.org/10.1007/s11356-015-4871-2

13. Xu R, Qafoku NP, Van Ranst E, et al (2016) Chapter One - Adsorption Properties of Subtropical and Tropical Variable Charge Soils: Implications from Climate Change and Biochar Amendment. In: Sparks DL (ed) Advances in Agronomy. Academic Press, pp 1–58

14. Yu O-Y, Raichle B, Sink S (2013) Impact of biochar on the water holding capacity of loamy sand soil. Int J Energy Environ Eng 4:44. https://doi.org/10.1186/2251-6832-4-44

15. Huang H, Cai W-L, Zheng Q, et al (2020) Gas permeability in soil amended with biochar at different compaction states. IOP Conf Ser: Earth Environ Sci 463:012073. https://doi.org/10.1088/1755-1315/463/1/012073

16. Novak JM, Busscher WJ, Laird DL, et al (2009) IMPACT OF BIOCHAR AMENDMENT ON FERTILITY OF A SOUTHEASTERN COASTAL PLAIN SOIL

17. Mollinedo J, Schumacher TE, Chintala R (2015) Influence of feedstocks and pyrolysis on biochar's capacity to modify soil water retention characteristics. Journal of Analytical and Applied Pyrolysis 114:100–108. https://doi.org/10.1016/j.jaap.2015.05.006

18. Karhu K, Mattila T, Bergström I, Regina K (2011) Biochar addition to agricultural soil increased CH4 uptake and water holding capacity – Results from a short-term pilot field study. Agriculture, Ecosystems & Environment 140:309–313. https://doi.org/10.1016/j.agee.2010.12.005

19. Bruun EW (2011) Application of fast pyrolysis biochar to a loamy soil - Effects on carbon and nitrogen dynamics and potential for carbon sequestration

20. Gopal P, Bordoloi S, Ratnam R, et al (2019) Investigation of infiltration rate for soil-biochar composites of water hyacinth. Acta Geophys 67:231–246. https://doi.org/10.1007/s11600-018-0237-8

21. Garg A, Xing X, Bordoloi S (2020) Water retention models for soils mixed with waste residues: application of the modified van-Genuchten and Brooks-Corey models. Biomass Conv Bioref. https://doi.org/10.1007/s13399-020-00957-x

22. Yang CD, Lu SG (2021) Effects of five different biochars on aggregation, water retention and mechanical properties of paddy soil: A field experiment of three-season crops. Soil and Tillage Research 205:104798. https://doi.org/10.1016/j.still.2020.104798

23. Liu Z, Dugan B, Masiello CA, Gonnermann HM (2017) Biochar particle size, shape, and porosity act together to influence soil water properties. PLOS ONE 12:e0179079. https://doi.org/10.1371/journal.pone.0179079

24. Razzaghi F, Obour PB, Arthur E (2020) Does biochar improve soil water retention? A systematic review and meta-analysis. Geoderma 361:114055. https://doi.org/10.1016/j.geoderma.2019.114055

25. Saffari N, Hajabbasi MA, Shirani H, et al (2021) Influence of corn residue biochar on water retention and penetration resistance in a calcareous sandy loam soil. Geoderma 383:114734. https://doi.org/10.1016/j.geoderma.2020.114734

26. Yi S, Chang NY, Imhoff PT (2020) Predicting water retention of biochar-amended soil from independent measurements of biochar and soil properties. Advances in Water Resources 142:103638. https://doi.org/10.1016/j.advwatres.2020.103638

27. de Jesus Duarte S, Glaser B, Pellegrino Cerri CE (2019) Effect of Biochar Particle Size on Physical, Hydrological and Chemical Properties of Loamy and Sandy Tropical Soils. Agronomy 9:165. https://doi.org/10.3390/agronomy9040165

28. Alghamdi AG, Alkhasha A, Ibrahim HM (2020) Effect of biochar particle size on water retention and availability in a sandy loam soil. Journal of Saudi Chemical Society 24:1042–1050. https://doi.org/10.1016/j.jscs.2020.11.003

29. Hussain R, Garg A, Ravi K (2020) Soil-biochar-plant interaction: differences from the perspective of engineered and agricultural soils. Bull Eng Geol Environ. https://doi.org/10.1007/s10064-020-01846-3

30. Lei O, Zhang R (2013) Effects of biochars derived from different feedstocks and pyrolysis temperatures on soil physical and hydraulic properties. J Soils Sediments 13:1561–1572. https://doi.org/10.1007/s11368-013-0738-7

31. Ouyang L, Wang F, Tang J, et al (2013) Effects of biochar amendment on soil aggregates and hydraulic properties. Journal of soil science and plant nutrition 13:991–1002. https://doi.org/10.4067/S0718-95162013005000078

32. Wong JTF, Chen Z, Chen X, et al (2017) Soil-water retention behavior of compacted biochar-amended clay: a novel landfill final cover material. J Soils Sediments 17:590–598. https://doi.org/10.1007/s11368-016-1401-x

33. Abel S, Peters A, Trinks S, et al (2013) Impact of biochar and hydrochar addition on water retention and water repellency of sandy soil. Geoderma 202–203:183–191. https://doi.org/10.1016/j.geoderma.2013.03.003

34. Bordoloi S, Gopal P, Boddu R, et al (2019) Soil-biochar-water interactions: Role of biochar from Eichhornia crassipes in influencing crack propagation and suction in unsaturated soils. Journal of Cleaner Production 210:847–859. https://doi.org/10.1016/j.jclepro.2018.11.051

35. Hardie M, Clothier B, Bound S, et al (2014) Does biochar influence soil physical properties and soil water availability? Plant Soil 376:347–361. https://doi.org/10.1007/s11104-013-1980-x

36. Kumar H, Huang S, Mei G, Garg A (2021) Influence of feedstock type and particle size on efficiency of biochar in improving tensile crack resistance and shear strength in lean clayey soil. International Journal of Damage Mechanics 30:646–661. https://doi.org/10.1177/1056789521991194

37. Ganesan SP, Bordoloi S, Ni J, et al (2020) Exploring implication of variation in biochar production on geotechnical properties of soil. Biomass Conv Bioref. https://doi.org/10.1007/s13399-020-00847-2

38. Kumar H, Cai W, Lai J, et al (2020) Influence of in-house produced biochars on cracks and retained water during drying-wetting cycles: comparison between conventional plant, animal, and nano-biochars. J Soils Sediments 20:1983–1996. https://doi.org/10.1007/s11368-020-02573-8

39. Kushvaha V, Kumar SA, Madhushri P, Sharma A (2020) Artificial neural network technique to predict dynamic fracture of particulate composite. Journal of Composite Materials 54:3099–3108. https://doi.org/10.1177/0021998320911418

40. Sharma A, Kushvaha V (2020) Predictive modelling of fracture behaviour in silica-filled polymer composite subjected to impact with varying loading rates using artificial neural network. Engineering Fracture Mechanics 239:107328. https://doi.org/10.1016/j.engfracmech.2020.107328

41. Wani I, Sharma A, Kushvaha V, et al (2020) Effect of pH, Volatile Content, and Pyrolysis Conditions on Surface Area and O/C and H/C Ratios of Biochar: Towards Understanding Performance of Biochar Using Simplified Approach. Journal of Hazardous, Toxic, and Radioactive Waste 24:04020048. https://doi.org/10.1061/(ASCE)HZ.2153-5515.0000545

42. Albaradeyia I, Hani A, Shahrour I (2011) WEPP and ANN models for simulating soil loss and runoff in a semi-arid Mediterranean region. Environ Monit Assess 180:537–556. https://doi.org/10.1007/s10661-010-1804-x

43. Cai W, Kumar H, Huang S, et al (2020) ANN Model Development for Air Permeability in Biochar Amended Unsaturated Soil. Geotech Geol Eng 38:1295–1309. https://doi.org/10.1007/s10706-019-01091-w

44. Filippis LACD, Serio LM, Mummolo FF and G (2017) ANN Modelling to Optimize Manufacturing Process. Advanced Applications for Artificial Neural Networks. https://doi.org/10.5772/intechopen.71237

45. Sharma A, Madhushri P, Kushvaha V, Kumar A (2020) Prediction of the Fracture Toughness of Silicafilled Epoxy Composites using K-Nearest Neighbor (KNN) Method. In: 2020 International Conference on Computational Performance Evaluation (ComPE). pp 194–198

46. Vasu NN, Lee SR, Lee D, Park JY (2016) ANN based estimation of SWCC fitting parameters for Korean weathered soil considering in-situ characteristics. The 2016 World Congress on Advances in Civil, Environmental, and Materials Research (ACEM16)

47. Zainal AK, Fadhil S (2018) Prediction of soil water characteristic curve using artificial neural network: a new approach. MATEC Web of Conferences 162:01014. https://doi.org/10.1051/matecconf/201816201014

48. Johari A, Hooshmand A (2015) Prediction of soil-water characteristic curve using gene expression programming. Iranian Journal of Science and Technology Transaction B: Engineering 39:

49. Johari A, Javadi AA (2011) Prediction of soil-water characteristic curve using neural network

50. Bordoloi S, Garg A, Sreedeep S, et al (2018) Investigation of cracking and water availability of soil-biochar composite synthesized from invasive weed water hyacinth. Bioresource Technology 263:665–677. https://doi.org/10.1016/j.biortech.2018.05.011

51. Garg A, Bordoloi S, Ni J, et al (2019) Influence of biochar addition on gas permeability in unsaturated soil. Géotechnique Letters 9:66–71. https://doi.org/10.1680/jgele.18.00190

52. Garg A, Huang H, Cai W, et al (2021) Influence of soil density on gas permeability and water retention in soils amended with in-house produced biochar. Journal of Rock Mechanics and Geotechnical Engineering 13:593–602. https://doi.org/10.1016/j.jrmge.2020.10.007

53. Ni JJ, Bordoloi S, Shao W, et al (2020) Two-year evaluation of hydraulic properties of biochar-amended vegetated soil for application in landfill cover system. Science of The Total Environment 712:136486. https://doi.org/10.1016/j.scitotenv.2019.136486

54. Gogoi D, Bordoloi N, Goswami R, et al (2017) Effect of torrefaction on yield and quality of pyrolytic products of arecanut husk: An agro-processing wastes. Bioresour Technol 242:36–44. https://doi.org/10.1016/j.biortech.2017.03.169

55. Masto RE, Kumar S, Rout TK, et al (2013) Biochar from water hyacinth (Eichornia crassipes) and its impact on soil biological activity. CATENA 111:64–71. https://doi.org/10.1016/j.catena.2013.06.025

56. Sharma A, Anand Kumar S, Kushvaha V (2020) Effect of aspect ratio on dynamic fracture toughness of particulate polymer composite using artificial neural network. Engineering Fracture Mechanics 228:106907. https://doi.org/10.1016/j.engfracmech.2020.106907

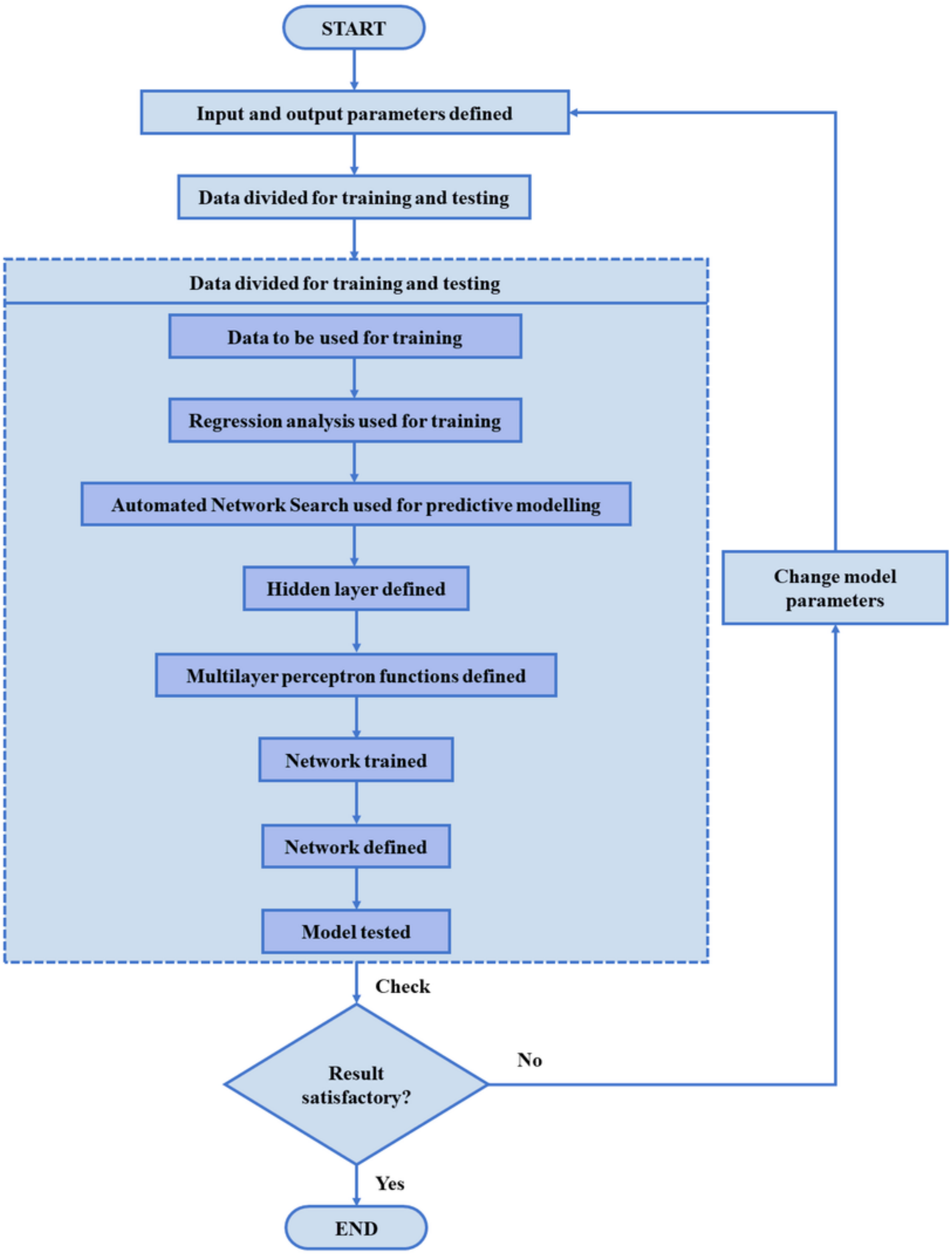
57. Schoonover JE, Crim JF (2015) An Introduction to Soil Concepts and the Role of Soils in Watershed Management. Journal of Contemporary Water Research & Education 154:21–47. https://doi.org/10.1111/j.1936-704X.2015.03186.x

58. Villagra-Mendoza K, Horn R (2018) Effect of biochar addition on hydraulic functions of two textural soils. Geoderma 326:88–95. https://doi.org/10.1016/j.geoderma.2018.03.021

59. Edeh IG, Mašek O, Buss W (2020) A meta-analysis on biochar's effects on soil water properties – New insights and future research challenges. Science of The Total Environment 714:136857. https://doi.org/10.1016/j.scitotenv.2020.136857

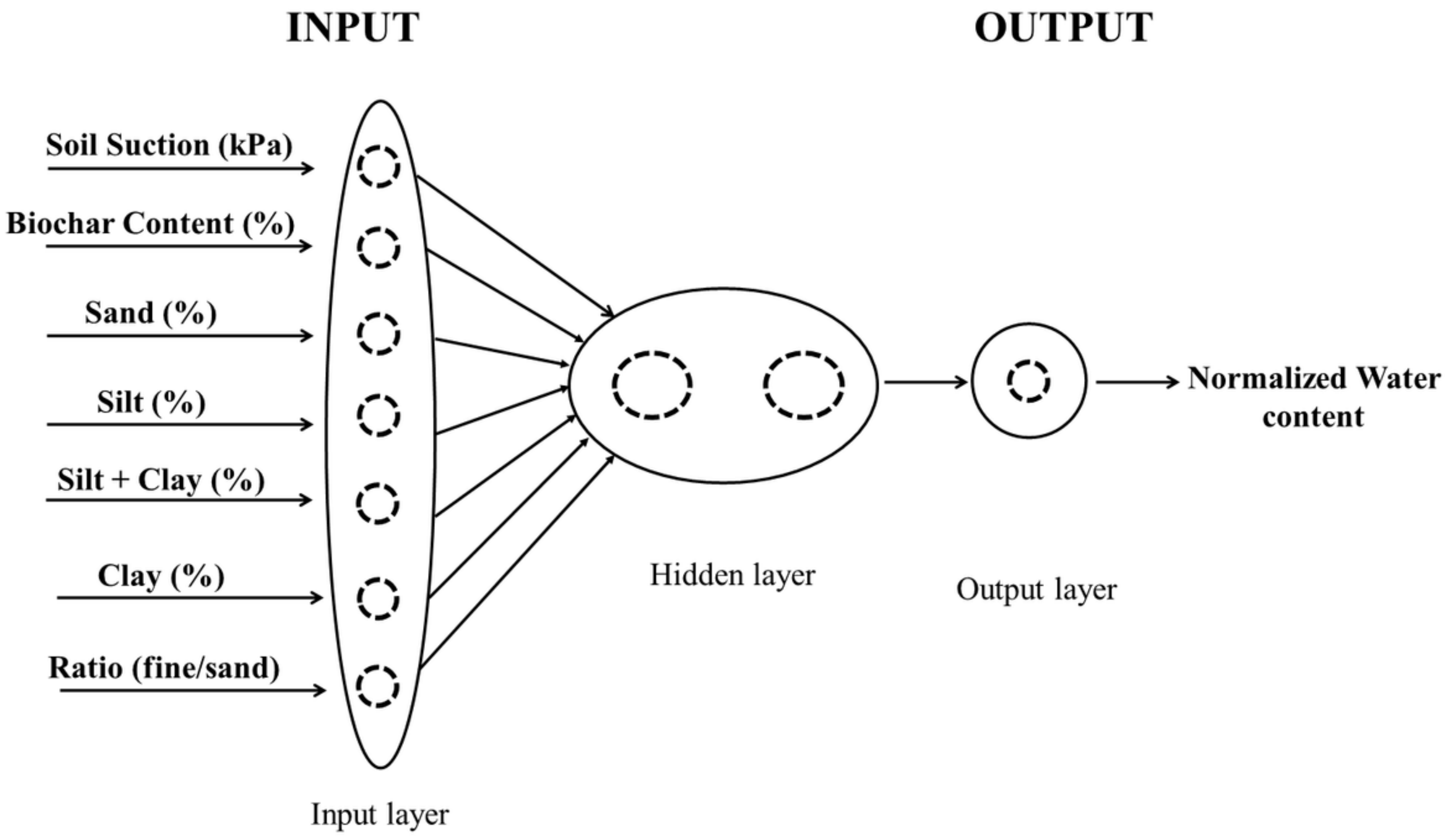
60. Arthur E, Tuller M, Moldrup P, de Jonge LW (2015) Effects of biochar and manure amendments on water vapor sorption in a sandy loam soil. Geoderma 243–244:175–182. https://doi.org/10.1016/j.geoderma.2015.01.001

# Figures



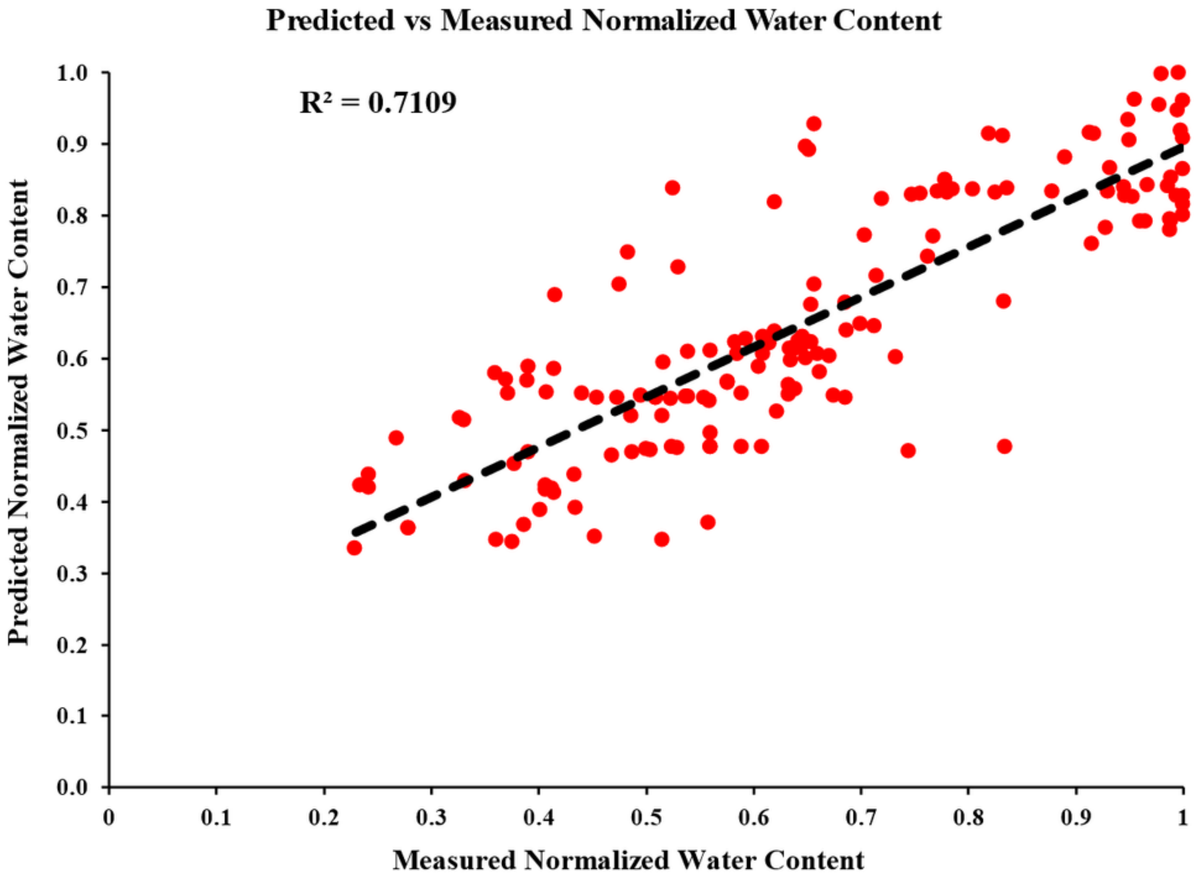

## Figure 1

Flowchart for ANN modelling



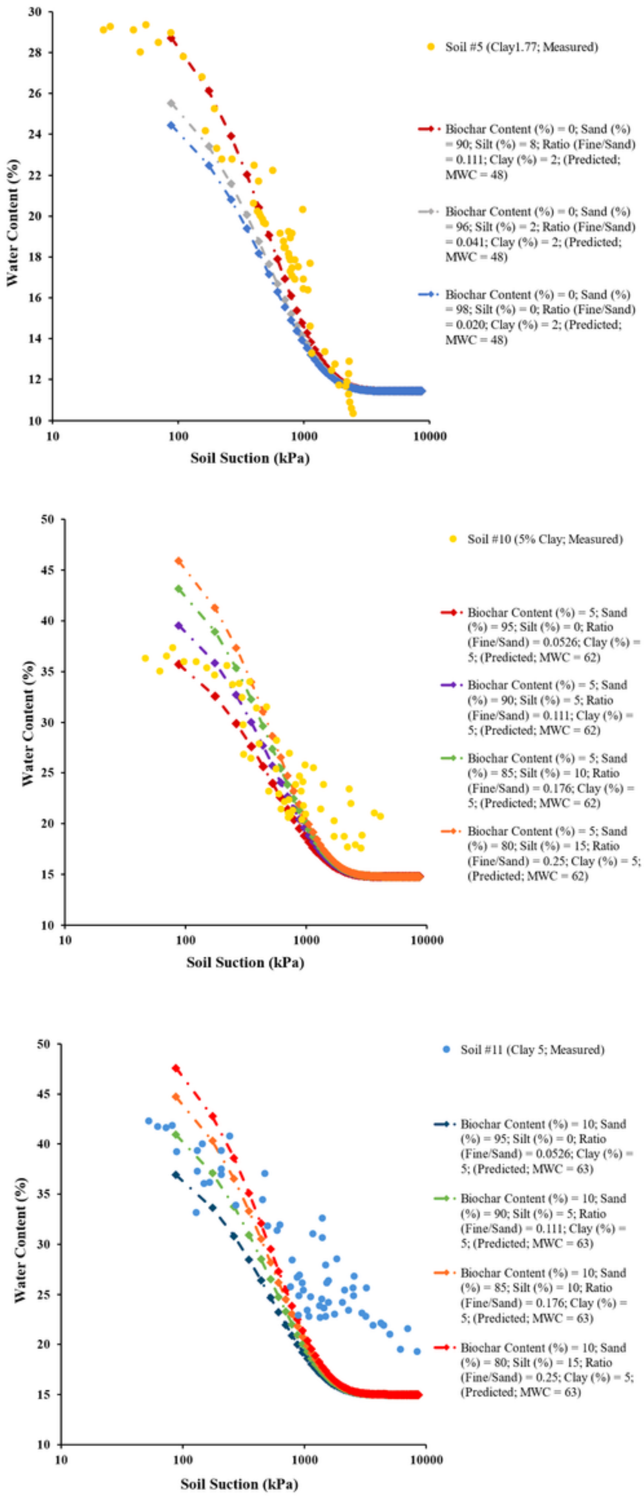

### Figure 2

ANN architecture used for the prediction of normalized water content



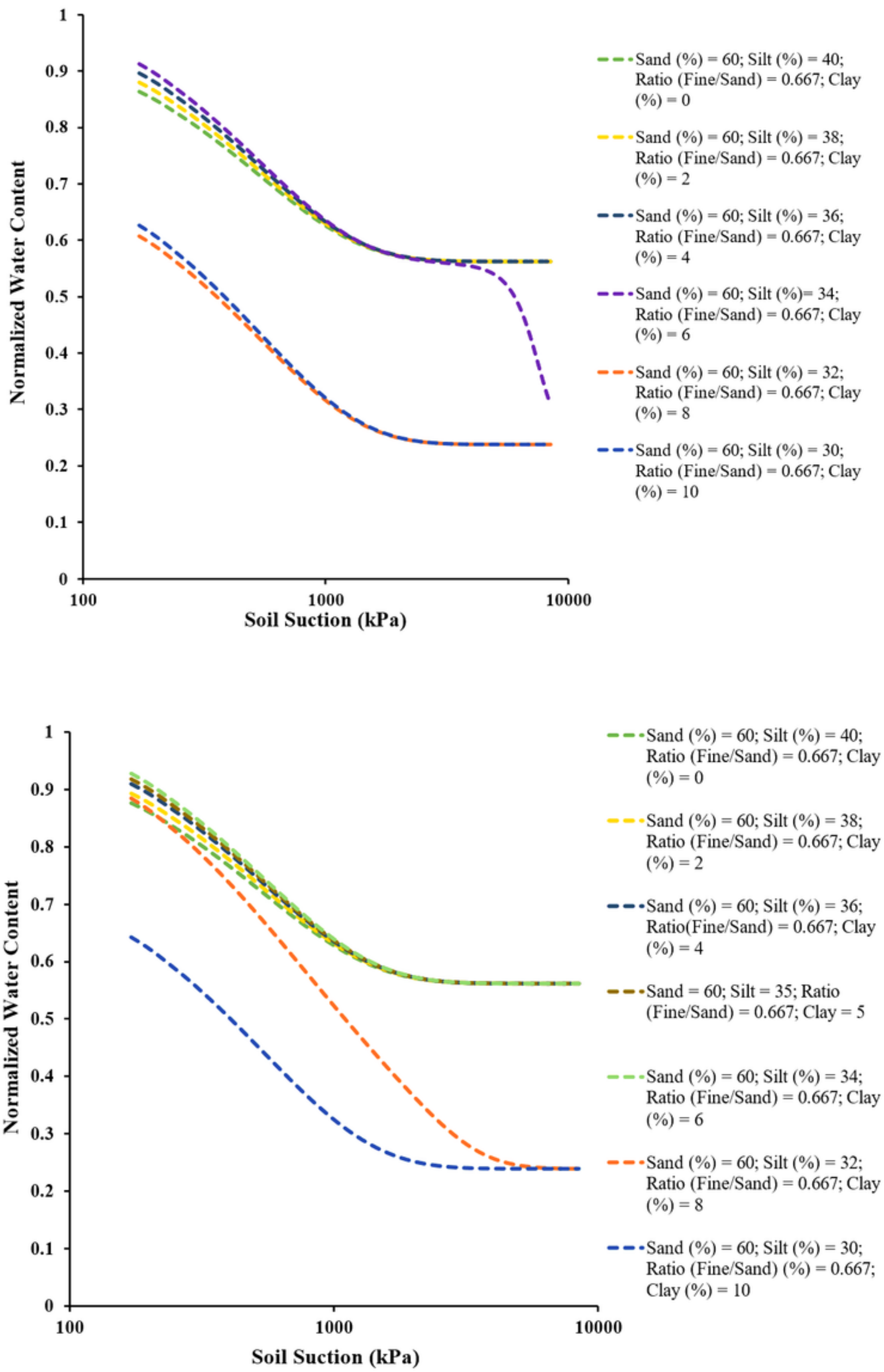

## Figure 3

Variation between Predicted Normalized Water Content and Measured Normalized Water Content (R2)



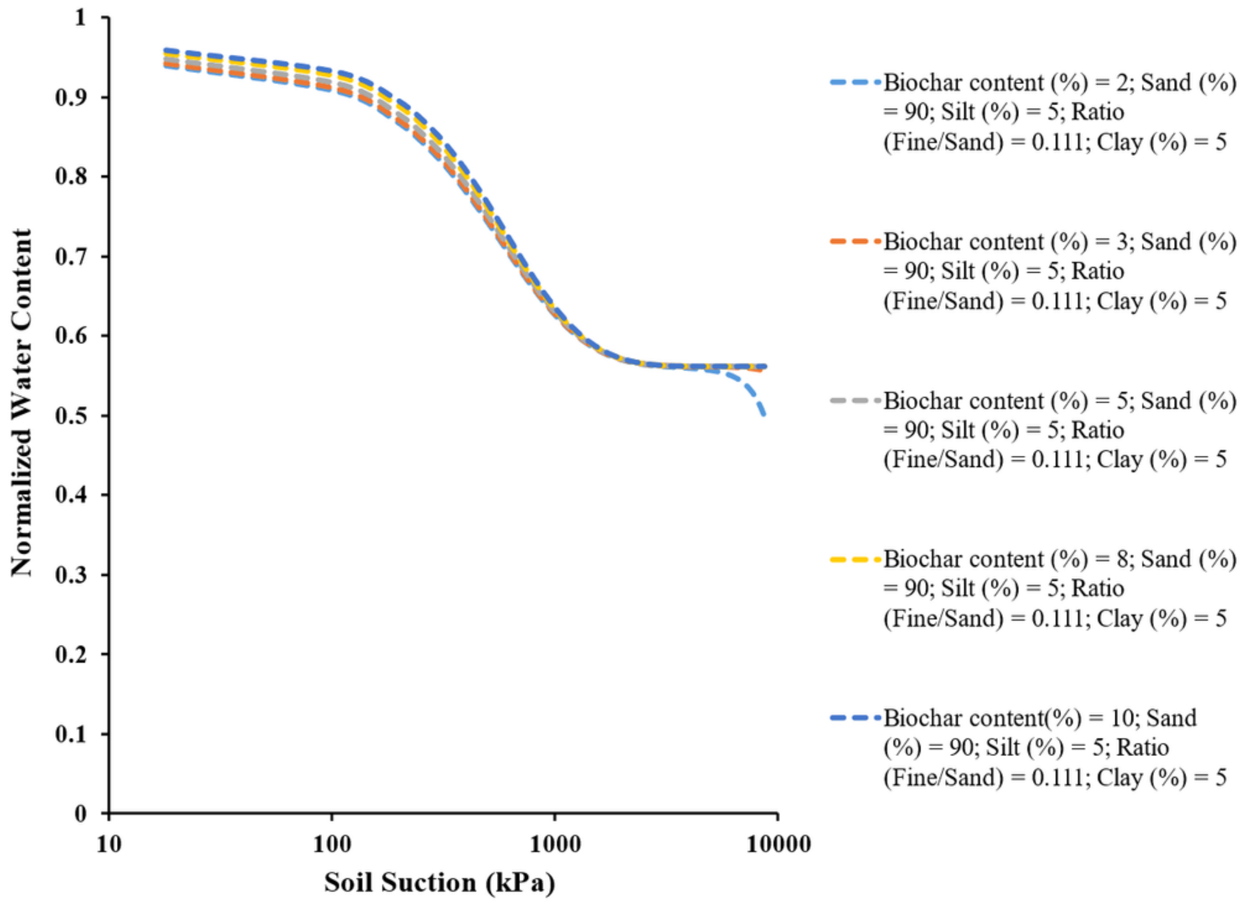

## Figure 4

Comparison of measured and predicted SWCCs corresponding to biochar content of (a) 0%, (b) 5% and (c) 10%



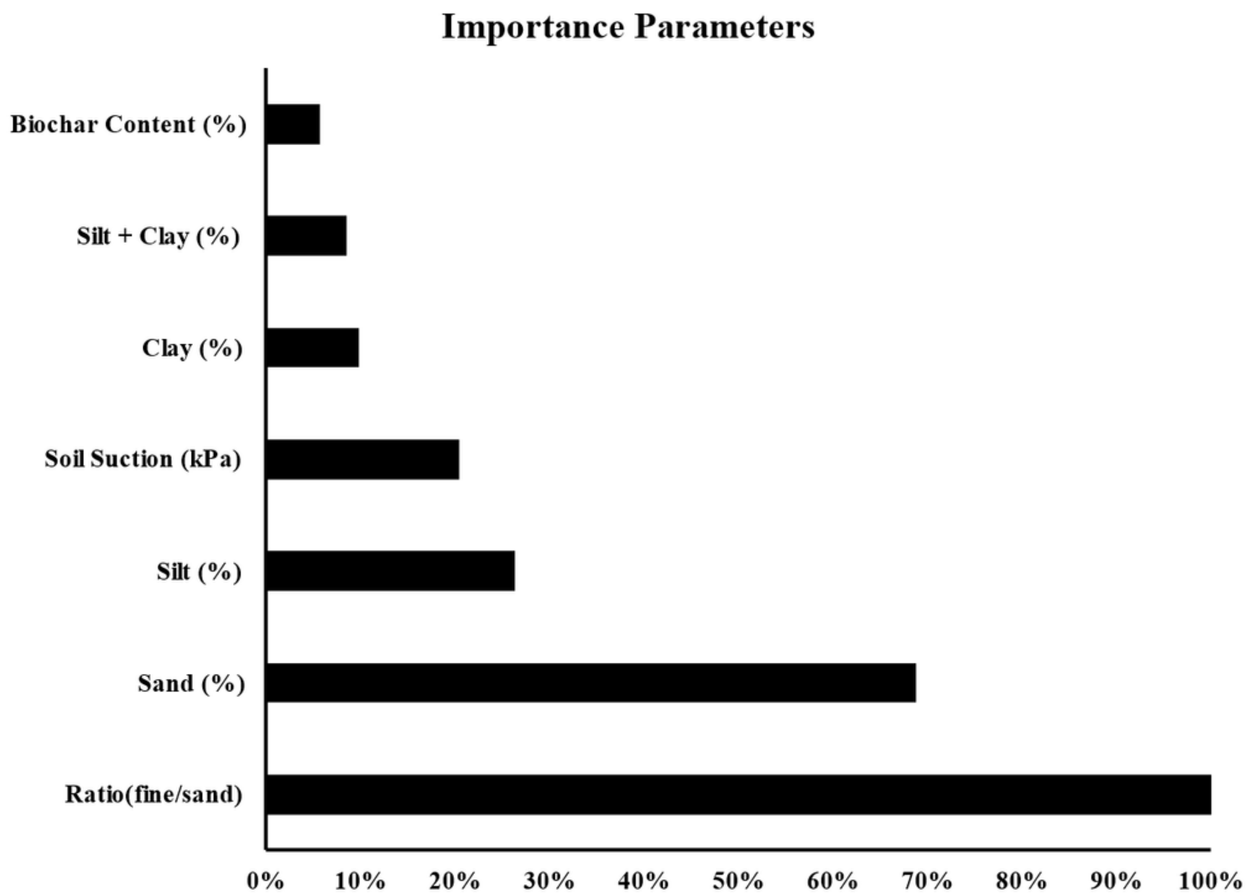

## Figure 5

Variation of normalized water content and soil suction for at different combinations of clay and silt contents for biochar content of (a) 3% and (b) 10%




## Figure 6

Variation of NWC and soil suction at different biochar content for soil with higher sand content




## Figure 7

Relative significance of parameters affecting SWCCs