PROCEEDINGS of the
23rd International Congress on Acoustics

9 to 13 September 2019 in Aachen, Germany

The influence of organic matter on acoustical properties of soil

Kamrun Nahar SURAVI[1,2], Ho-Chul SHIN[2]; Keith ATTENBOROUGH[1]; Shahram TAHERZADEH[1];
William Richard WHALLEY[2]
[1]Open University, United Kingdom
[2]Rothamsted Research, United Kingdom

ABSTRACT

Organic matter influences physical and mechanical properties of soils. Samples collected from a long-term agriculture experiment involving different treatments, have been subjected to differential thermal analysis (DTA) to deduce the organic matter content and its composition. Water release characteristics and soil strength have been measured with the suction plate method and indirect tension method, respectively. Impedance tube measurements made on sand samples with various water content show that soil surface absorption decreases with increasing water content. Changes in absorption coefficient spectra deduced from impedance tube measurements on soil samples extracted from the long-term agriculture experiment involving different organic matter content but similar water content, are consistent with predictions of the effects of changes in porosity and permeability in rigid-porous air-filled media.

Keywords: Soils, Porosity, Permeability

1. INTRODUCTION

Soil is a complex porous elastic medium. Structural properties of soil (porosity, pore size distribution, tortuosity, air permeability etc.) can be regulated by different factors (both biotic and abiotic). It has been observed that organic matter had a strong interaction with physical properties of soil such as porosity and resistance, mechanical stresses (1). Poor structural condition of soil (compaction, degradation) can restrict plant growth and affect crop yield. So, it is very important in agricultural research to have reliable information and knowledge regarding physical properties and structural stability of soil (2). In this study, we are observing the physical behavior of long-term agricultural soil including pore-related properties, water retention, mechanical properties etc. and trying to identify the impact of organic matter and nitrogen applications on soil structure-related properties. To achieve our research goal, we adopted different measurement techniques, commonly used in soil physics and engineering. Acoustical excitation provides a non-invasive alternative to the classical methods used in soil physics and can be utilized to determine properties of soil (2, 3, 4, 5, 6). Sound wave propagation through soils is a mechanical phenomenon that causes a small perturbation without altering the fabric of soils (7). Attenborough and colleagues (4) found that sound can penetrate through soil due to surface porosity and associated air permeability and thus to be absorbed and undergo phase change through friction and thermal exchanges between the pore fluid and the surrounding solid. Sound propagation in soil or any porous media is influenced by its texture, structure, roughness, degree of compaction and the moisture content (3, 5, 7, 8, 9). Acoustical techniques have been used to study the formation of surface crusts (10).

Classical Biot theory for a porous and elastic medium (11, 12) predicts the existence of three wave types in the porous medium: two types of dilatational or compressional waves (1st and 2nd kind) and one rotational or shear wave. In a soil consisting of a dense solid frame with a low-density fluid, such as air saturating the pores, the first kind of dilatational wave, often called the 'fast' wave which is characterized by particle motion in phase with fluid motion, has a velocity very similar to the 2nd dilatational wave (or "P" wave in geophysics) travelling in the drained frame. However, the attenuation of the first dilatational wave type is higher than that of the P wave in the drained frame. The extra attenuation comes from the viscous forces in the pore fluid acting on the pore walls. This first dilatational wave has negligible dispersion and its attenuation is proportional to the square of the frequency, as is the case also for the rotational wave. If fast waves are excited predominantly, viscous

---

[1] kamrun.suravi@open.ac.uk
[2] kamrun.suravi@rothamsted.ac.uk

coupling at pore walls means that some of their energy is carried in the pore fluid as the second type of dilatational wave or ‘slow’ wave. In air-saturated soils, the second dilatational wave, often called the ‘slow’ wave, has a much lower velocity than the first. The attenuation of the ‘slow’ wave stems not only from viscous forces at the pore walls but from thermal exchange with the pore walls. In the rigid-frame limit, theory predicts a single ‘slow’ wave which governs the acoustical properties of rigid-framed porous solids and is the wave type responsible for the acoustical properties of sound absorbing materials (13). Models for the acoustical properties of rigid-porous media introduce several parameters such as the tortuosity of the pore space, porosity, viscous characteristic length, thermal characteristic length, flow resistivity and dynamic shape factors (14, 15).

2. METHODS AND MATERIALS

2.1 Soil sampling and preparation

In this study, we collected top-soils (0-23 cm) from Broadbalk wheat experiment (51° 48´ 32.14´´ N, 0° 22´ 15.21´´ W) – the world’s oldest long-term experiment (since 1843) in Rothamsted Research, Harpenden, UK in late October 2018. Four plots on section 9 of Broadbalk experiment were sampled to give a range of Soil Organic Matter (SOM) contents including: control plot (Nil), farm yard manure (FYM) plot, inorganic fertilizers plots with two levels of nitrogen (N) e.g., Mid Nitrogen plot N3 (NPKMg)- 48 Kg N per ha and highest nitrogen plot N6 (NPKMg)- 288 Kg N per ha. Soil Organic Carbon (SOC) content for Nil, FYM, N3 and N6 are 8.4, 31.75, 11.48 and 12.82 t/ha respectively. Prior to acoustic characterization, the soils were partially saturated by adding water by weight and suction plate data follow the water retention curves shown in Figure 1. The water retention characteristic is an important physical property controlled by pore geometry (16). Figure 1 shows that soil samples with higher organic matter content have higher water retention.

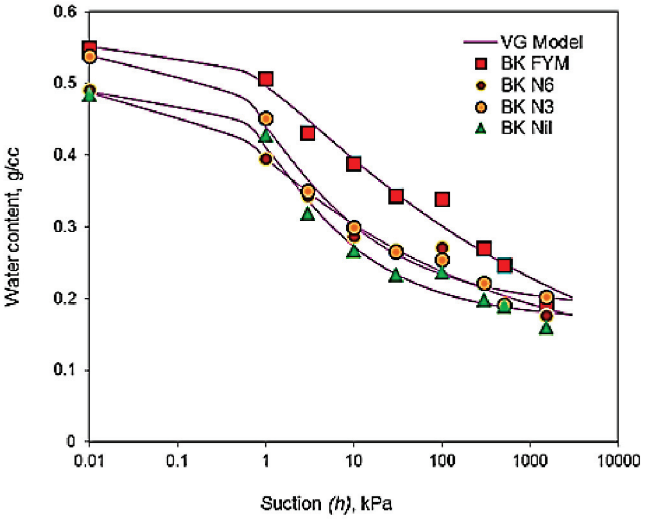

Figure 1 – Water retention characteristics fitted with van Genuchten model (17), of soil samples from the Broadbalk experiment (BK)

The soil samples were air-dried and passed through 2 mm mesh sieve. Initial water content for air-dry soils were very low and quite similar. The water content for Nil, FYM, N3 and N6 air-dry samples are 1.8%, 2.6%, 1.9% and 1.9% respectively. All partially saturated soils were allowed to equilibrate for at least 24 h in air-tight plastic bags at a constant temperature to prevent evaporation before impedance tube measurements. By using pneumatic pressure chamber immediately before the measurements, the dry and moist samples were packed to different densities into a sample holder with a hard base specially designed to fit with the impedance tube. The samples were about 40 mm thick.

2.2 Impedance tube measurements

In the impedance tube measurement, a loudspeaker is used to excite the sample with sound. And a microphone is used to measure the total pressure above the soil surface (10). In this study, we used a three microphone Bruel and Kjaer 100 mm impedance tube (Type BK 4206), operated in the widespacing mode (100 mm microphone spacing) in the frequency range between 50 and 1600 Hz, connected to a National Instruments data acquisition system. The impedance tube was set up vertically by screwing on to a laboratory wall shown in Figure 2.

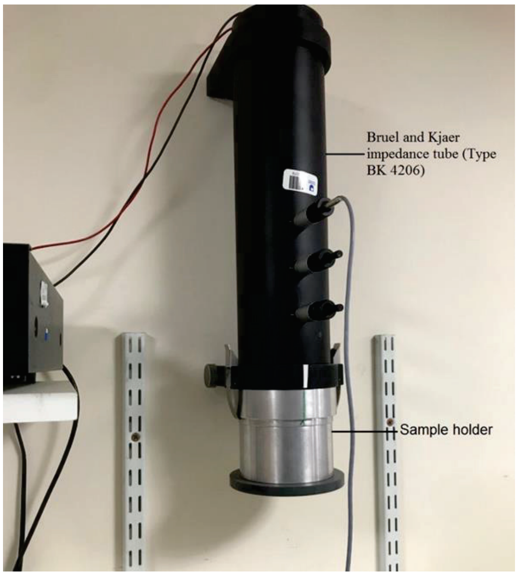

Figure 2 – Impedance tube set up

The 100 mm inner diameter sample holder was clamped to the impedance tube. In this study we used a single microphone method and a white noise signal and measured the transfer function of the acoustic pressure between two different positions in the measurement tube with the same microphone. The reflection coefficient of the reference plane is estimated from the transfer function. Finally, the impedance and normal incidence absorption coefficient are calculated from the reflection coefficient. The use of the same microphone for measuring the pressure at the two different positions does not require a relative calibration between two microphones. The data acquisition and processing were carried out with MatLab® codes.

Initially, measurements were made on 50 mm thick fine sand samples with different moisture content. The results (Figure 3) show that as the percentage of water in sand increases the absorption gradually decreases in agreement with Horoshenkov and Mohamed (18).

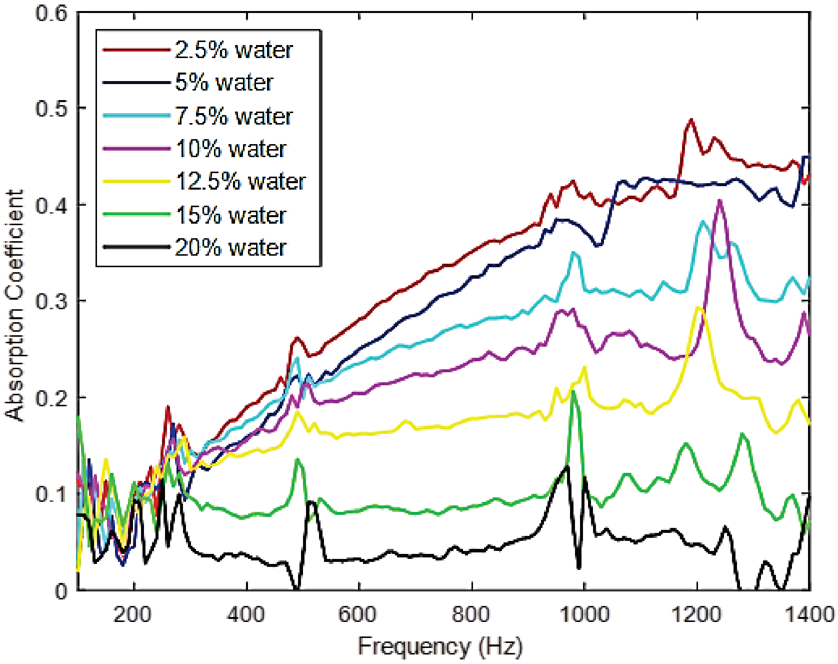

Figure 3 – Absorption coefficient spectra of fine sand samples with different water content

3. RESULTS WITH VARYING ORGANIC MATTER

3.1 Repeatability

First, we have considered the repeatability of the measurements. The example absorption spectra in Figure 4 show good repeatability between 200 Hz and 1400 Hz.

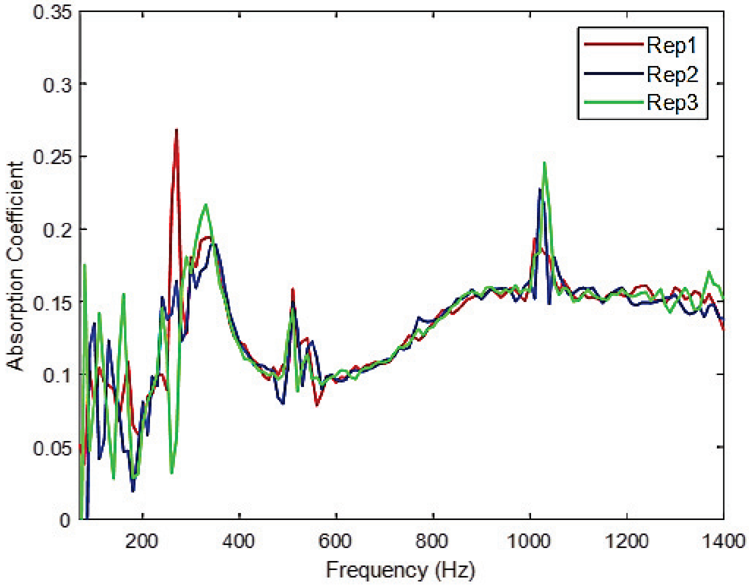

Figure 4 – Three repetitions of absorption coefficient deduced from measurements on FYM soil

3.2 Air-dry soils

Results of impedance tube measurements show that soils with minimal water content (air-dry soil) packed to same density (1.3 g/cc) but different organic matter content give rise to different absorption spectra. For the air-dry soil samples all the nitrogen treatments (even the control sample with no nitrogen) result in higher absorption than FYM (Figure 5).

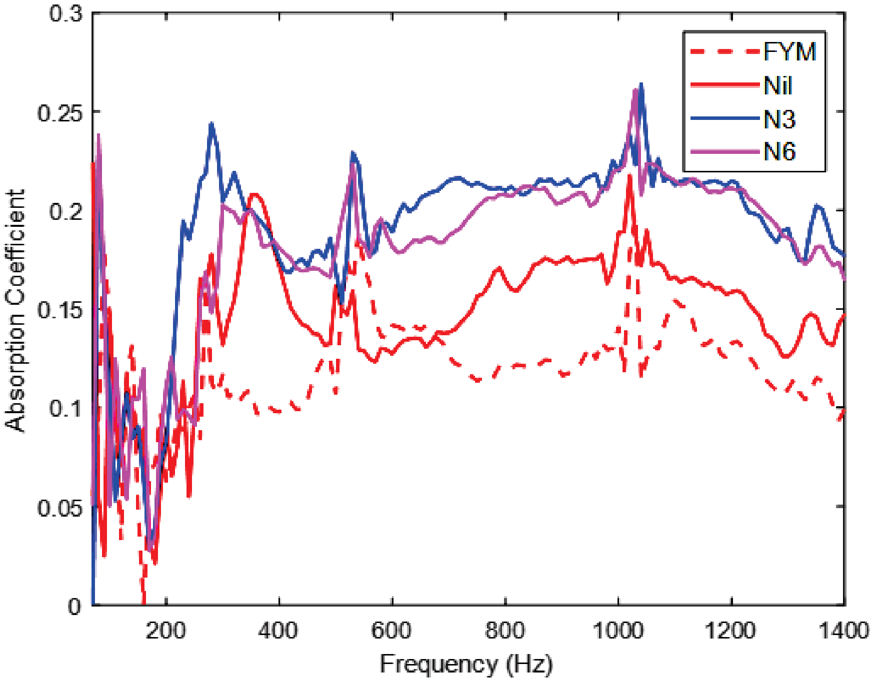

Figure 5 – Absorption coefficient spectra of 4 cm thick Air-dry soils with same packing density of 1.3 g/cc

On the other hand, when the dry soil samples were packed at 10 kPa pneumatic pressure, which implies lower densities, soils with high organic matter (FYM) along with higher nitrogen (N6) show higher absorption (Figure 6).

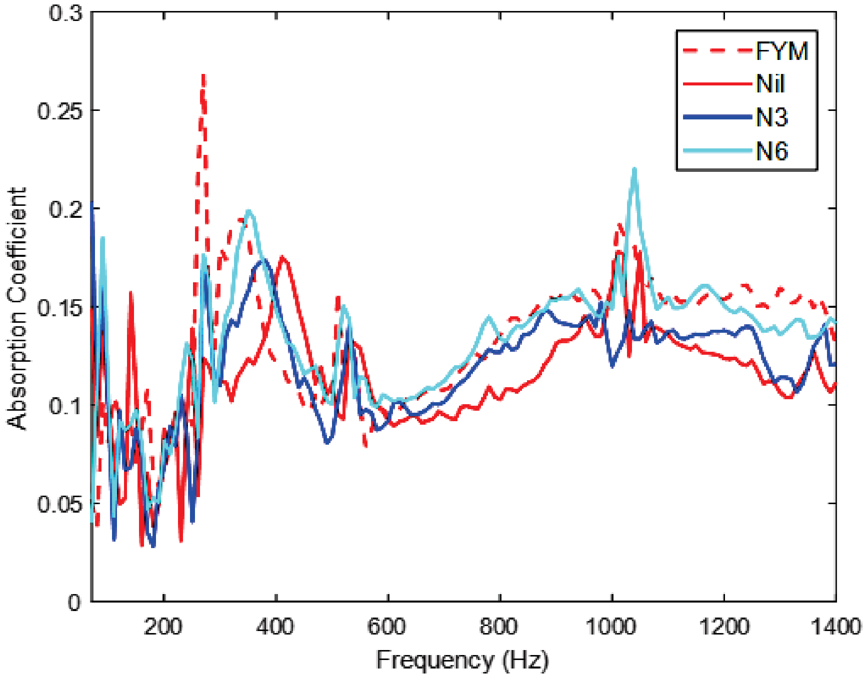

Figure 6 – Absorption coefficient spectra for air-dry soil samples packed at 10 kPa pressure

3.3 Effects of partial saturation

Also, results of measurements on partially saturated soils show that the absorption of soils treated with FYM has a strong dependence on water content. FYM gives higher absorption than N6 when water content is high and at same matric potential (Figure 7). But the same samples with reduced moisture content, i.e. in drier conditions, give higher absorption (Figure 8).

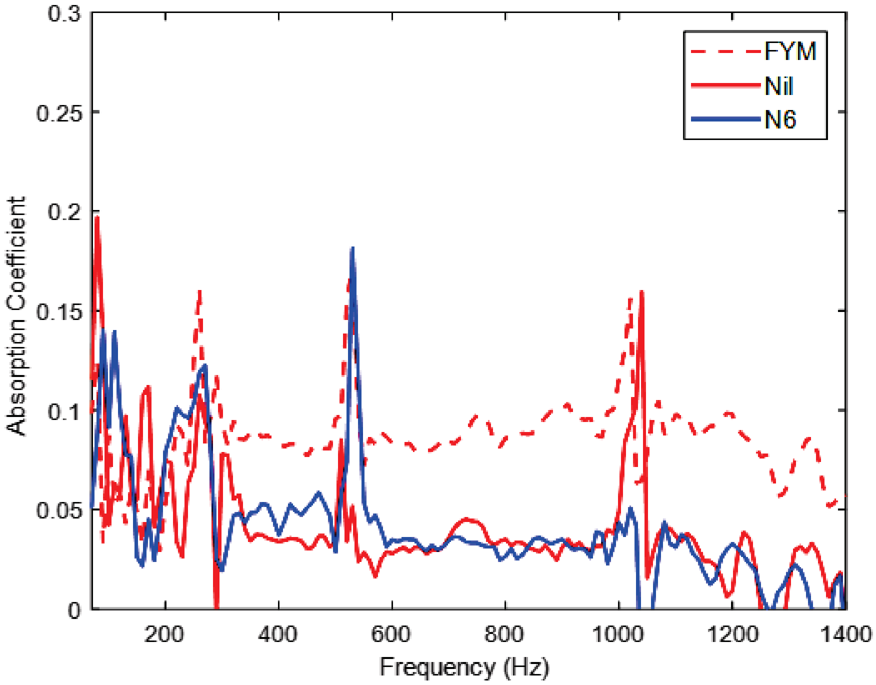

Figure 7 – Absorption coefficient spectra of soil samples with moisture content at –300 kPa matric potential and packed to 1.3 g/cc

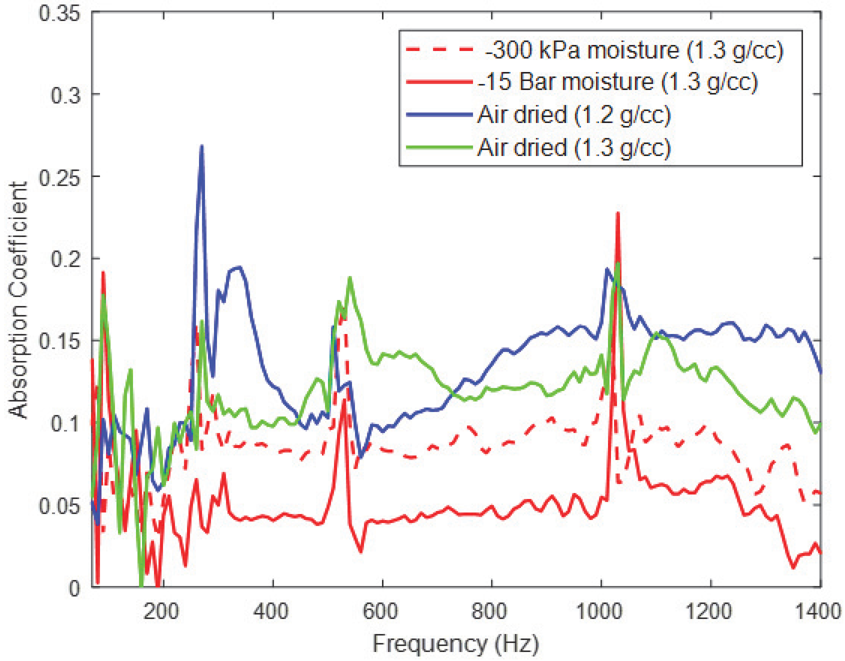

Figure 8 – Absorption coefficient spectra of FYM soil samples with different packing and moisture conditions

4. DISCUSSION

Velea and coworkers (19) investigated the effect of different saturation levels on the speed of compressional and shear waves in porous material. Also, Horoshenkov and Mohamed (18) found that changes in the acoustic surface admittance result from a relatively small change (from 0 to 15%) of the water content in sand as supported by the data in Figure 3.

It has been observed that organic matter particles fill in the coarse pore fraction to produce a greater number of fine pores and increased total porosity (20).

We have observed that soil samples with high organic matter show relatively high absorption of sound. The increase in measured absorption with organic matter is consistent with the predicted effects of increasing the porosity and permeability on the acoustical properties of a 4 cm thick rigid-porous hard-backed layer. Figures 9 and 10 show some representative predictions of the effects of changes in porosity and permeability using the Johnson-Champoux-Allard model (14,21).

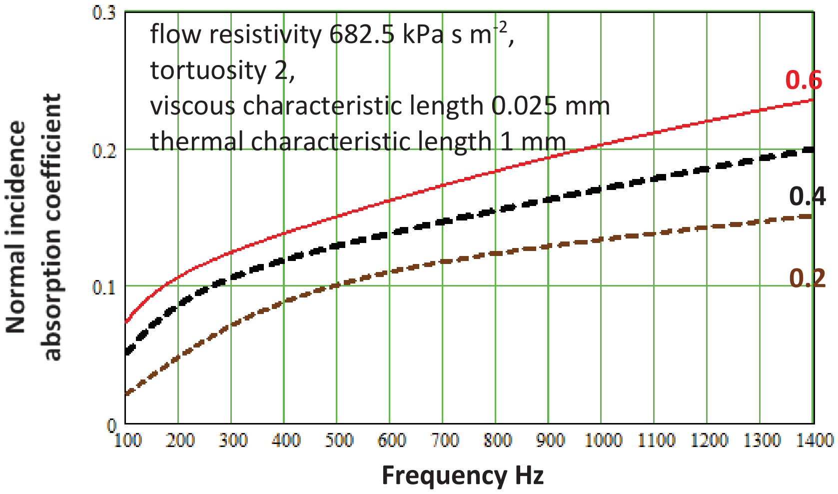

Figure 9 – Predicted effect of changes in porosity (assuming constant permeability etc.) on the normal incidence absorption coefficient of a 4 cm thick rigid-porous hard-backed layer.

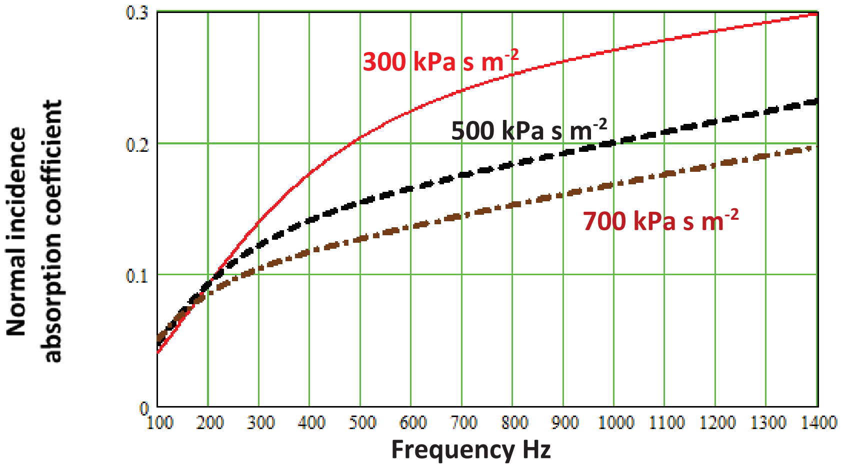

Figure 8 – Predicted effect of changes in flow resistivity (viscosity coefficient/permeability) assuming constant porosity 0.4 etc., on the normal incidence absorption coefficient of a 4 cm thick hard-backed layer.

In making these predictions, no attempt has been made to find best fit parameters for the measured absorption spectra other than to ensure that the predicted absorption coefficients have similar magnitudes to those measured. Furthermore, in the predictions, the characteristic lengths have been kept constant whereas, strictly, they should have been changed also. Nevertheless, these predictions suggest that the changes in absorption coefficient spectra observed in Figures 5 to 8 are consistent with the predicted effects of changes in porosity and permeability in a rigid-porous air-filled hard-backed layer.

5. CONCLUSION

It has been confirmed that different levels of moisture content cause variations in the acoustical characteristics of both sand and soil. Moreover, the acoustical results of increasing organic matter content in soil are consistent with increasing porosity and permeability. While this has implications for the potential variations of ground effect over cultivated soils, it is also of interest to the use of non-invasive sound reflection for monitoring soil condition. Further work will involve deducing physical parameters from the acoustical data for various soil states and comparing the acoustically-deduced values with those obtained by other means.

ACKNOWLEDGEMENTS

William Richard Whalley and Ho-Chul Shin are supported by the BBSRC Designing Future Wheat project (BB/P016855/1) and the BBSRC/NERC ASSIST project (NE/N018117/1). Kamrun Suravi is funded jointly by Rothamsted Research and the Open University.

REFERENCES

1. Chakraborty D, Watts CW, Powlson DS, Macdonald AJ, Ashton RW, White RP, Whalley WR. Triaxial testing to determine the effect of soil type and organic carbon content on soil consolidation and shear deformation characteristics. Soil Sci Soc Am J. 2014;78(4):1192-1200.
2. Moore HM, Attenborough K. Acoustic determination of air filled porosity and relative air permeability of Soils. J Soil Sci. 1992; 43:211-228.
3. Oelze ML, O'Brien WD, Darmody RG. Measurement of attenuation and speed of sound in soils. Soil Sci Soc Am J. 2002;66(3):788-796.
4. Attenborough K, Bashir I, Taherzadeh S. Outdoor ground impedance models. J Acoust Soc Am. 2011;129(5):2806-2819.
5. Sharma RK, Gupta AK. Continuous wave acoustic method for determination of moisture content in agricultural soil. Comput electron agric. 2010;73(2):105-111.
6. Shin H-C, Taherzadeh S, Attenborough K, Whalley WR, Watts CW. Non-invasive soil parameter deduction using acoustic-seismic coupling and linear Biot-Stoll theory. Eur J Soil Sci. 2013;64 :308 – 323
7. Zhiqu L, Sabatier JM..Effects of soil water potential and moisture content on sound speed. Soil Sci Soc Am J. 2009;73(5): 1614-1625.
8. Voronina NN, Horoshenkov KV. A new empirical model for the acoustic properties of loose granular

media. Appl Acoust. 2003; 64:415–432.

9. Attenborough K, Taherzadeh S. Propagation from a point source over a rough finite impedance boundary. J Acoust Soc Am. 1995; 98:1717–1722.
10. Leary D, David AD, Craig JH. Acoustic techniques for studying soil‐surface seals and crusts. Ecohydrol. 2009;2(3): 257-262.
11. Biot MA. Theory of propagation of elastic waves in a fluid saturated porous solid. I. Low-frequency range. J Acoust Soc Am. 1956; 28:168–178.
12. Biot MA. Theory of propagation of elastic waves in a fluid‐saturated porous solid. II. Higher frequency range. J Acoust Soc Am. 1956;28(2): 179-191.
13. Attenborough K. On the Acoustic Slow Wave in Air-filled Granular Materials. J Acoust. Soc Am. 1987;81(1):95-102.
14. Champoux Y, Stinson MR. On acoustical models for sound propagation in rigid frame porous materials and the influence of shape factors. J Acoust Soc Am. 1992;92(2): 1120-1131.
15. Attenborough K. Models for the acoustical properties of air-saturated granular media. Acta acústica. 1993;1: 213-226.
16. Gregory AS, Bird NR, Whalley WR, Matthews GP, Young IM. Deformation and shrinkage effects on the soil water release characteristic. Soil Sci Soc Am J. 2010;74(4):1104-1112.
17. van Genuchten MT. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Sci Soc Am J. 1980;44(5):892-898.
18. Horoshenkov KV, Mohamed M H. Experimental investigation of the effects of water saturation on the acoustic admittance of sandy soils. J Acoust Soc Am. 2006;120(4): 1910-1921.
19. Velea, D, Shields FD, Sabatier JM. Elastic wave velocities in partially saturated Ottawa sand: Experimental results and modelling. Soil Sci Soc Am J. 2000; 64:1226–1234.
20. Zhang B, Horn R, Hallett PD. Mechanical resilience of degraded soil amended with organic matter. Soil Sci Soc Am J. 2005;69(3): 864-871.
21. Allard J.-F., Propagation of sound in porous media, 1993, Elsevier Applied Science