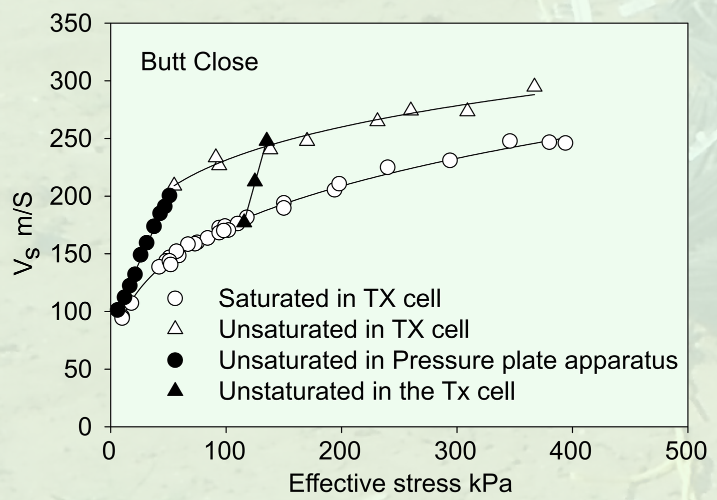
The opportunities elastic waves offer to soil science

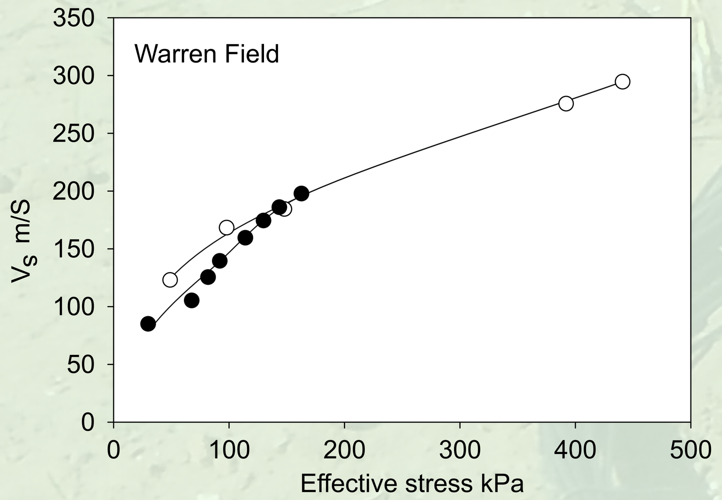
William R. Whalley[1], Dick Jenkins[2], Ho-Chul Shin[3], Chris W. Watts[1], Shahram Taherzadeh[4], Weida Gao[5], Tusheng Ren[6] and Keith Attenborough[7]

(1)Rothamsted, Milton Keynes, United Kingdom, (2)Delta-T Devices, Cambridge, United Kingdom, (3)Open University, Milton Keynes, United Kingdom, (4)Open University, Milton Keynes, United Kingdom, (5)China Agricultural University, Beijing, China, (6)Department of Soil & Water, China Agricultural University, Beijing, China, (7)Open University, Milton Keynes, United Kingdom

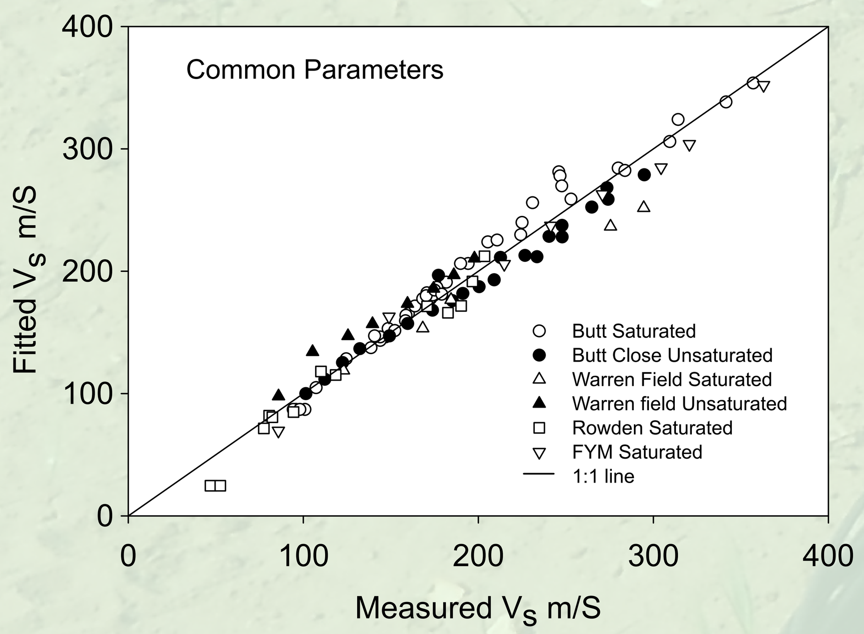
We demonstrate the potential of a non-invasive measurement technique for the in situ monitoring of soil physical properties in the field. When soils are regarded as porous and elastic media, sub-surface wave propagation can be indicative of the soil status. Such propagation can be initiated by airborne sound through acoustic-to-seismic (A–S) coupling. Measurements of near-surface sound pressure and acoustically induced soil particle motion can be exploited to estimate the pore-related and elastic properties of soils. Measured data were compared with model predictions based on wave propagation in layered homogeneous isotropic poroelastic media described by linear Biot-Stoll theory. Soil properties were estimated through an optimization process minimizing the differences between the measurements and predictions. The fitted soil characteristics are air permeability, porosity, P-/S-wave speeds (related to bulk and rigidity moduli) and a loss factor. Layer depth was also estimated for multi-layered samples.

Shear wave velocity





$$V_s = A\frac{(F_e - e)^2}{1+e}\left(\sigma_s^r - \psi\left(\frac{\psi}{\psi_{ae}}\right)^{-0.55}\right)^{\Upsilon}$$



e is the void ratio

F is the void ratio normalization factor

ψ_{ae} is the air entry potential

ψ is the matric is the matric potential to which the soil has dried

σ_s applied stress

A, r, and ϒ are adjustable parameters

Penetrometer resistance

On the premise that $Q = k\ \rho V^2$ we fitted

$$Q = \rho\left(A^*\frac{(F_e - e)^2}{1+e}\left(\sigma_s^{\,p} - \psi\left(\frac{\psi}{\psi_{ae}}\right)^b\right)^f\right)^2$$

Here *F, A*, p, f* and *b* are empirical, adjustable parameters

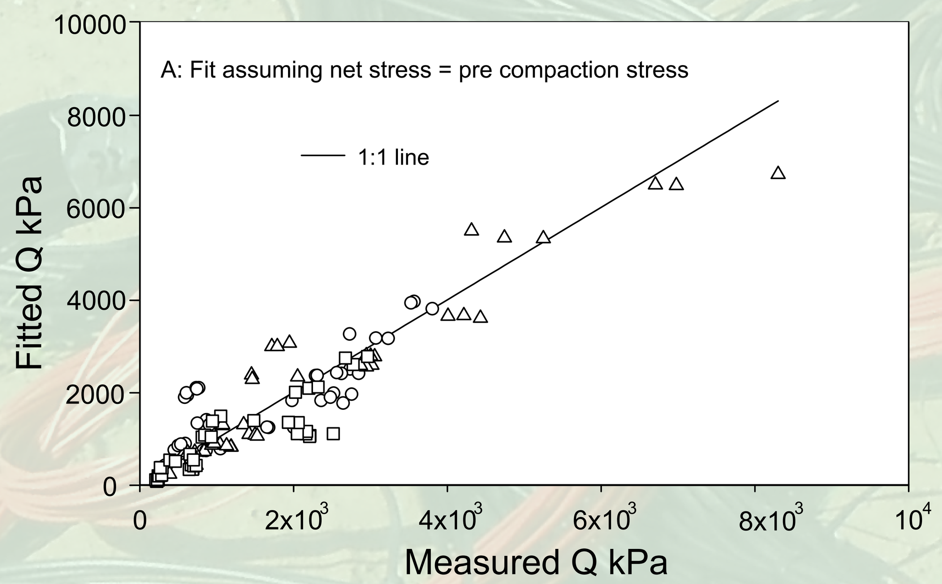
e is void ratio

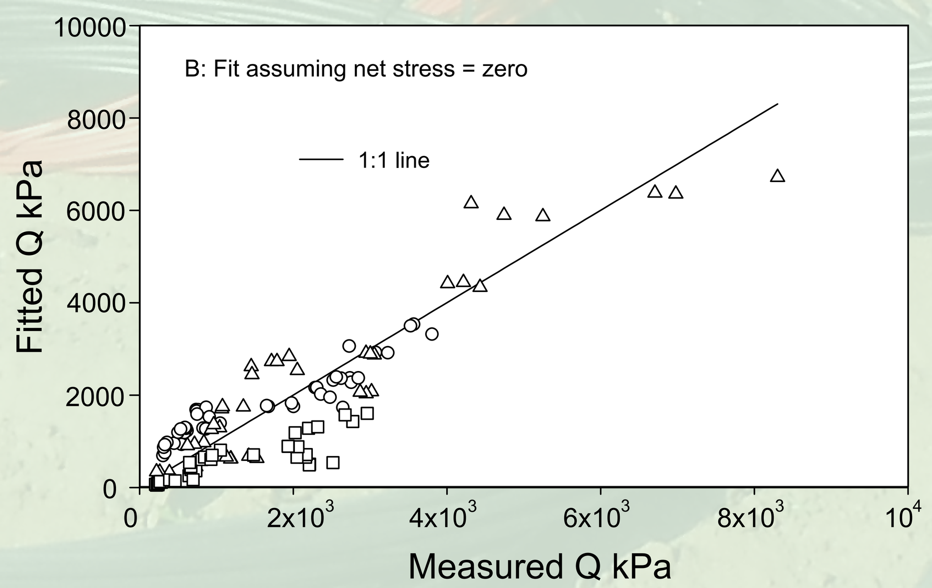
σ is the applied pressure

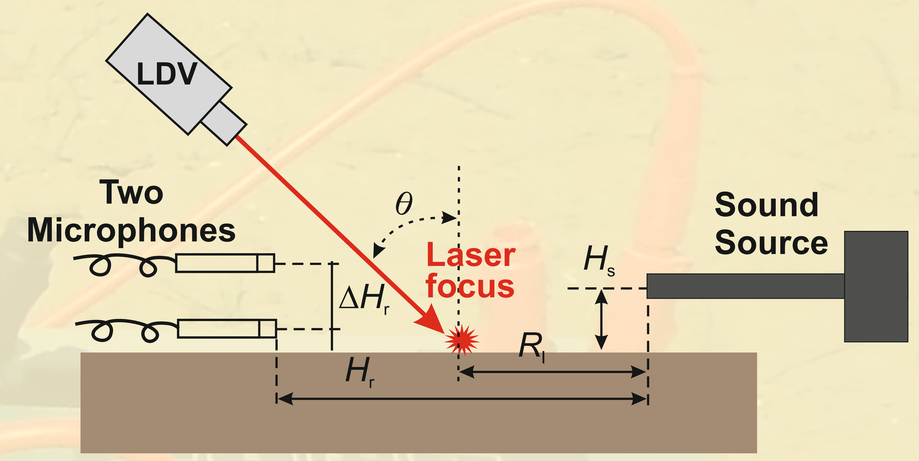
e and σ are related with the compression characteristic

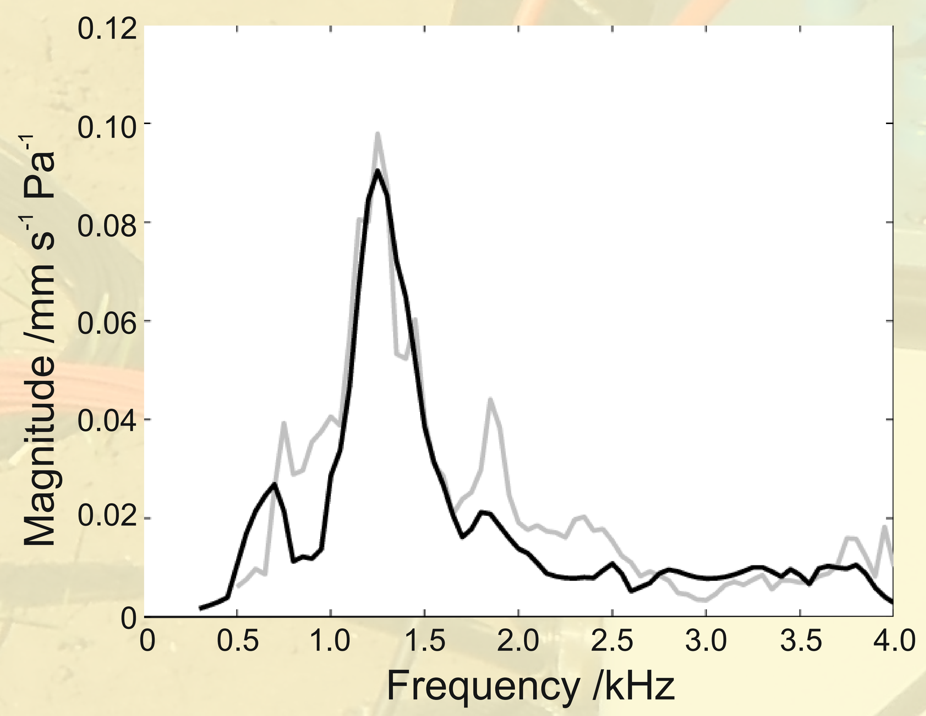
Ψ is the matric potential

Ψae is the air entry potential

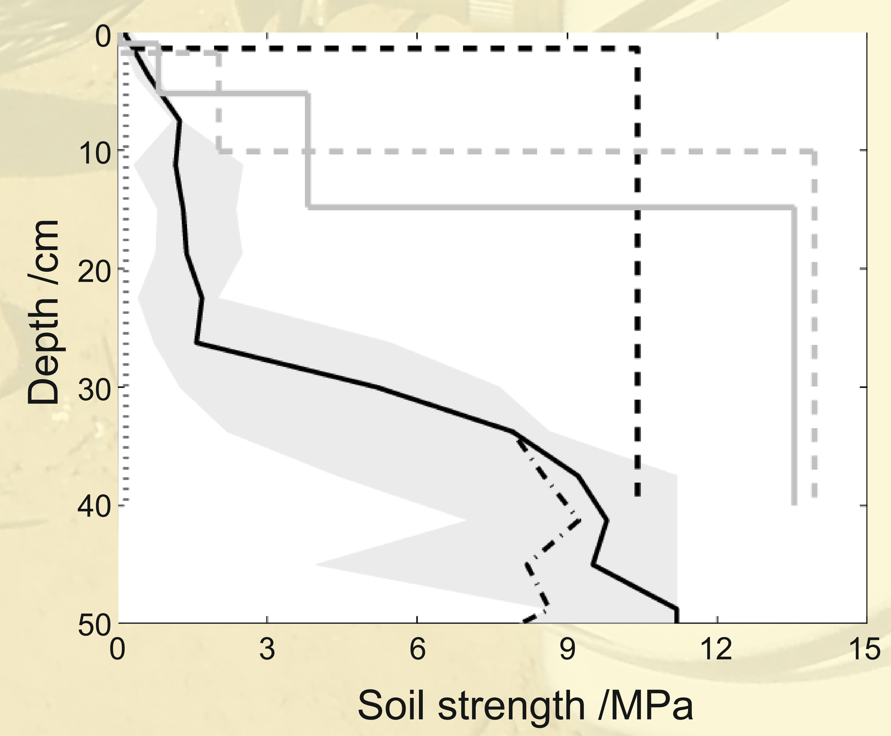








Comparisons of the measurement (in grey) and the two-layer simulation (in black) based on the deduced parameters for a cleared plot at a Rothamsted Research experimental site: (a), level difference; (b), acoustic-to-seismic coupling.



Field soil strength measured by a penetrometer and deduced by optimizations. The penetrometer data were collected in an Experimental plot 20 m away from the location of the acoustic-to-seismic measurement. The solid black line is the median of five penetrometer readings by assigning 80 kgf to the failed readings which are discarded for the separated dash/dot black line. The surrounding greyed area shows theminimum and maximum readings at each depth. The vertical dotted black line was deduced under the single-layer assumption during optimization; the dashed black line under the two-layer assumption; the dashed grey line under the three-layer assumption; the solid grey line under the four-layer assumption.

Whalley, W.R., Jenkins M., and Attenborough, K. (2012) The velocity of shear waves in unsaturated soil. Soil and Tillage Research. 125: 30-37

Gao, W., Watts C.W., Ren, T. and Whalley, W.R. (2012) The effects of compaction and soil drying on penetrometer resistance. Soil and Tillage Research. 125: 14–22

Whalley, W.R., Jenkins M., and Attenborough, K. (2012) The velocity of shear waves in unsaturated soil. Soil and Tillage Research. 125: 30-37

Gao, W., Watts, C.W., Ren, T., Shin, H.-C., Taherzadeh, S., Attenbororugh, K., Jenkins, M. and Whalley, W.R. (2013) Estimating penetrometer resistance and matric potential from the velocities of shear and compression waves. Soil Science Society of America Journal. 77: 721–728

Shin, H.-C., Taherzadeh, S., Attenborough, K., Whalley W. R. and C. W. Watts 2013) Non-invasive soil parameter deduction using acoustic-seismic coupling and linear Biot-Stoll theory. European Journal of Soil Science. 64: 308-323.

Whalley, W.R., Ober, E.S. and Jenkins, M. (In press) Measurement of the matric potential of soil water in the rhizosphere. Journal of Experimental Botany In press