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PERSPECTIVES

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HYDROGEOPHYSICS FOR AGRICULTURE: CAPABILITIES AND LIMITATIONS

The following paper was presented by IAgrE Student member, Guillaume Blanchy *(Lancaster University/ Rothamsted Research)* **to the IAgrE South Midlands Branch in February 2019. The co-authors of the paper are Chris Watts** *(Rothamsted Research)* **and Andrew Binley** *(Lancaster Environment Centre, Lancaster University)*

Wheat is one of the most important global crops, being grown on more land than any other commercial crop, and currently providing 20% of total calories consumed by humans worldwide, being second only to rice. A 60% increase in demand is expected by 2050, as the global population increases towards 10 billion.

Designing Future Wheat is a collaboration of several UK organisations, namely Rothamsted Research, John Innes Centre, the Earlham Institute, NIAB, Institute of Food Research, the University of Bristol, the University of Nottingham and EMBL-EBI.As part of the project, scientists are seeking to identify traits tolerant to UK drought and temperature stress scenarios. We need to know how soil structure and the availability of nutrients and water interact with genotypes to permit deep rooting.

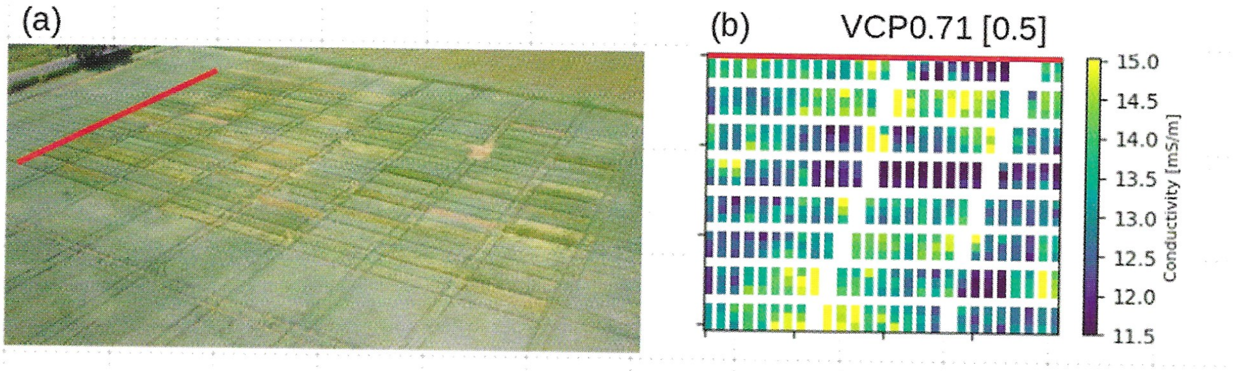
To facilitate this study, agricultural engineers are developing a number of practical and innovative technologies for in-field above and below ground phenotyping, including use of drones, robots and other ground-based systems.

One of the more challenging aspects of this study is to discover how wheat roots interact with the soil. Here we explain how we are using hydrogeophysics methods to non-destructively rapidly screen hundreds of wheat varieties in the field.

What is hydrogeophysics?

Many people in the UK will associate geophysics with archaeology from the popular TV series *Time Team*. In fact, geophysics is a very broad discipline of Earth sciences. Hydrogeophysics focusses on the investigation of properties and processes in the Earth that are related to hydrology (the study of Earth's water). Hydrogeophysics uses a range of techniques, many of which were developed for mineral exploration, to 'look into the ground' and improve our understanding of where water is, where it is moving and what is controlling it. Methods based on sensing electrical properties are popular in hydrogeophysics because the presence of water (or its movement) can be detected by changes or variation in electrical properties (a wet soil conducts electricity easier than a dry soil).

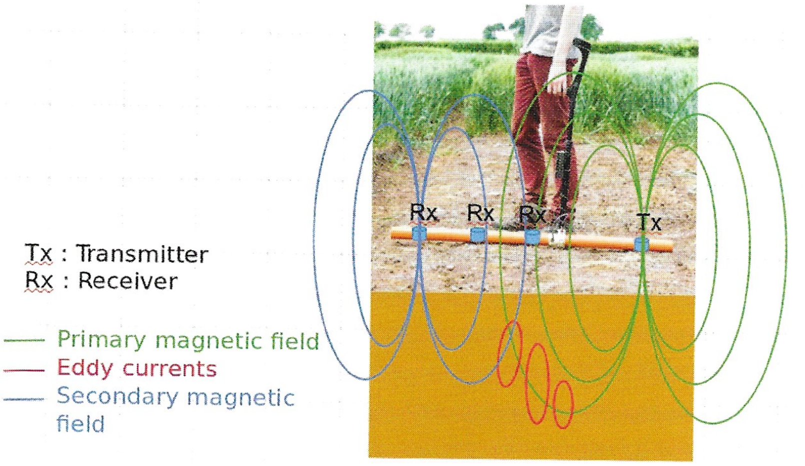
We can measure electrical properties of the soil without disturbing it, which makes the technique particularly attractive in agriculture. In fact, commercial systems are available today using arrays of coulter-electrodes towed behind a tractor to measure soil electrical conductivity (the property of the soil that describes the ease at which electrical current will move



Picture (a) of the 216 plot field experiment consisting of 71 wheat varieties + fallow plot replicated three times. (b) Background measurement of apparent electrical conductivity measured at 0.5 m depth with the VCP0.71 coil configuration revealing field patterns associated with different soil textures. Note 2 diagonal lines represent previously unknown buried high voltage cables

through it).

Another method, called electromagnetic induction (EMI), doesn't need any contact with the soil and works a bit like a metal detector. It is actually used for very large scale studies, such as mineral prospecting, using sensors mounted on aircraft.



Internal working of the EMI device (CMD Mini-Explorer). The primary field is created by the transmitter. Electrical conductors in the soil create 'eddy currents' which can be sensed by a secondary magnetic field at the receiver coils.

How are we using hydrogeophysics?

The attraction here, however, is that from EMI measurements close to the ground surface we can map variation in soil electrical conductivity at shallow depths. And since the presence of water effects soil conductivity then perhaps we can monitor changes in the amount of soil water (due to uptake by crops) without even touching the soil.

If we can do this then perhaps we can assess how different varieties of wheat extract water from the soil (how much and how deep?).

How does EMI work?

We are currently using a CMD mini-explorer electromagnetic conductivity sensor (GF Instruments, supplied by Allied Associates, Dunstable, UK). This device is composed of a tube with different coils inside: one transmitter coil (Tx) and three receiver coils (Rx1, Rx2 and Rx3).

EMI instruments measure an apparent electrical conductivity, $_a$ This represents the weighted average of soil electrical conductivity over a depth range that depends on the separation distance between the transmitter and receiver coils, as well as their orientation. The transmitter coil creates an electromagnetic field, which when it enters the soil creates a signal that can be sensed on the receiver coils and allow us to determine the ground electrical *apparent* conductivity.

Multi-coil devices allow the recording of different apparent conductivities over different depths. We can use these measurements in a type of mathematical modelling called *inverse modelling* to obtain a depth-specific electrical conductivity.

How to use it to measure root water uptake?

Soil moisture is a dynamic property under growing crops, dominated by root water extraction driven in turn by evapotranspiration. To monitor soil drying we use EMI surveys carried out regularly throughout the growing season to compare different varieties of wheat.

The first set of measurements are taken shortly after the crop emerges but when the soil is at field capacity: this is called the background survey. All subsequent surveys are expressed in changes in electrical conductivity to the initial background survey.

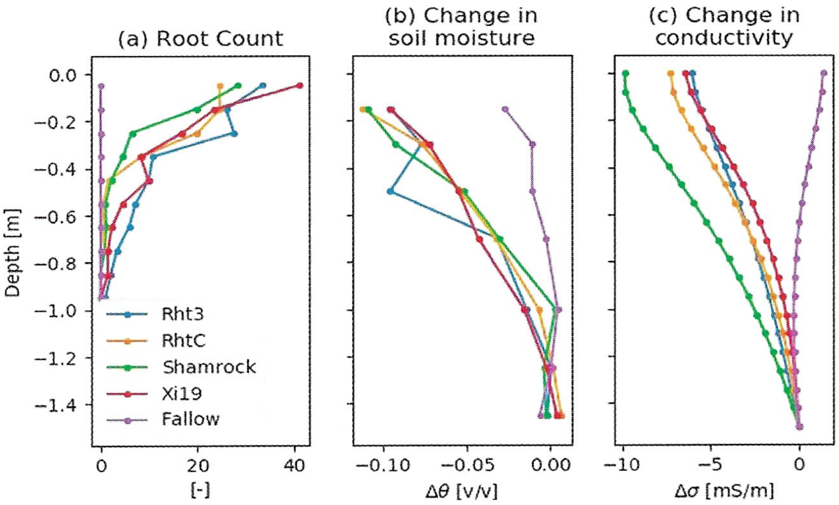
As all other soil properties stay virtually the same so changes in electrical conductivity are mainly driven by the changes in soil moisture, that can be related to root water uptake. The one exception is soil temperature which is measured continuously allowing a correction factor to be applied to the EMI output.

Additional measurements such as soil moisture content from neutron probes and root counts from the soil cores have been recorded to be compared to the EMI results. Figure 3 shows how the change in electrical conductivity from EMI is related to the change in soil moisture (from neutron probe). There is a particularly clear distinction in this case between the fallow plots and the cropped plots. Both electrical conductivity and soil moisture change also show very good agreement with the root counts obtained from soil coring. Note that all the different wheat varieties are very similar mainly because of there wasn't any major water stress during this growth season (2017).

What are the limitations of this approach?

During this work we have identified that the relationship between the transformed electrical conductivity and soil moisture content is highly site specific.

Hence, there is a need to establish a relationship for each field or even



Profiles of different wheat lines and fallow plot in term of (a) root count, (b) change in soil moisture from neutron probe and (c) change in electrical conductivity from EMI.

for different locations within the same field if the field soil is heterogeneous. e.g. clay-rich area will present a much higher increase in electrical conductivity with increasing soil moisture compared to sandy soil. Looking at change with time allows to overcome some of the static effects of the soil but not all.

The second main limitation is that apparent conductivity data measured from the EMI device needs to be post-processed to build a depth-specific electrical conductivity profile. This process called 'inversion' is well established for other hydrogeophysical methods but still to be improved for EMI. This forms part of my PhD.

Conclusion

In conclusion, hydrogeophysics provides a potentially useful tool for wheat root phenotyping under field conditions. In this article we have focused on the EMI method and shown how it offers us a high-throughput, non-invasive screening technique to compare soil drying profiles of different wheat varieties throughout the growing season. However, field-specific relationships are needed to obtain more accurate soil moisture results and the inversion of apparent conductivity to depth-specific electrical conductivity can still be improved. Overall, this method has a great potential for agricultural applications.

ACKNOWLEDGEMENTS

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2019 IAgrE Journalists Award

How to secure longer-lasting point and tine metal

The following article by James Andrews won the 2019 IAgrE Journalists Award. It was published in and is reproduced by kind permission of the Farmers Weekly. The article has been slightly abridged for Landwards and represents the author's views and are not necessarily endorsed by IAgrE.

Picking the right wearing metal for your cultivator or drill isn't always about plumping for the cheapest deal. James Andrews visits a UK firm that specialises in engineering longer-lasting and higher-performing alternatives

Soil engaging parts are one of those boringly inevitable expenses when running a cultivator or drill.

But while many shop around for the cheapest lumps of metal to haul through the ground, a company in North Yorkshire has been gathering a loyal group of followers for its harder-wearing premium versions.

JJ Metcalfe and son's offerings boast lifespans between four and 10 times that of conventional heat-treated steel and promise to maintain their performance until the point they're fit for the scrap bin.

Part of that's due to the designs company director Mike Metcalfe creates, but it's also helped significantly by the use of ultra-hard tungsten carbide at the main wear points.

Retrofit parts

JJ Metcalfe started out as an agricultural contracting outfit back in 1947, with Mike Metcalfe's father John at the helm. Most of his work centred on sugar beet production, but he was also a keen and successful match ploughman - this is where the family interest in cultivation equipment began.

After a stint as a rally driver and race-engine builder, Mike came back to the family business and began making parts for their sugar beet harvester. This then quickly grew into a sideline business as other contractors asked him to supply them.

But it was when he was asked to produce a lower-cost point for a Tim Howard subsoiler that he got into building parts for cultivators. He then quickly started doing work for other manufacturers including Heva and Simba, before moving on to selling retrofit parts for most brands of machine. The company now has a seven-strong team, including Mike's daughter Abi and son Jonny.

Tungsten Carbide

This wonder material is second in hardness only to industrial diamonds – as used on oilrig drill bits – and is apparently particularly effective