Monitoring of hydrodynamics under Conservation Agriculture in southern Africa using electrical resistivity imaging

NS31A-0765

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1 Conservation Agriculture (CA)

is based on the principles of:

Minimum soil disturbance | Soil cover using crop residue or live mulch | Crop rotation and/or intercropping

Conservation agriculture has been shown to:

Increase yields | Reduce runoff & flooding | Reduce soil erosion

2 Introduction

Southern Africa is facing a drying climate, with an increased risk of drought, combined with an increasing demand for food production in the future. Conservation Agriculture (CA) has been promoted by NGOs and governmental bodies - including the United Nations - due to its potential to increase yields in the face of reduced rainfall, amongst other benefits.

Despite the knowledge that CA can increase yields and reduce water runoff, little is known about how CA affects the behaviour of soil water. The CEPHaS project (Strengthening Capacity in Environmental Physics, Hydrology and Statistics for Conservation Agriculture Research) aims to start to answer some of these questions, which include:

- How does CA affect the soil water supply (and does this make crop production more resilient to delayed rains)?

- What impact (if any) does CA have on the recharge of groundwater?

In this poster, we show how Electrical Resistivity Tomography (ERT) is being used alongside soil physics sensors (soil water content etc.) to help answer these questions.

We use a resistivity imaging system developed by the British Geological Survey - PRIME (PRoactive Infrastructure Monitoring & Evaluation), shown in Fig. A - that allows measurements at sub-diurnal intervals, and automatic, remote transfer of data using mobile/cell telemetry. The high temporal frequency of the data collection allows for detailed spatial modelling of rapid hydrodynamic processes, while the remote data transfer, together with the ability of the PRIME system to be solar powered, enables the collection of data over a prolonged period that can extend for years.

Figure A - PRIME installations in Malawi & Zimbabwe

3 Timeline

July '18 — Installation of buried 2D ERT arrays in Zambia

October '18 — Installation of 3D cross-borehole ERT arrays in Malawi

November '19 — Installation of 3D surface ERT arrays in Zimbabwe

Now!

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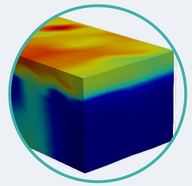
To December '21 — Twice daily dataset collection, delivered by remote telemetry

2022 onwards — ERT observatories remain after the project ends - the project legacy facilitates future research



4 Zambia - cross-sectional 2D ERT using buried electrodes

2 lines of 128 electrodes each have been installed in Zambia, enabling a 2D, cross-sectional resistivity model to be calculated beneath each array.

The baseline model in Fig. B shows a near-surface layer of low resistivity (weathered) material, above a laterally heterogeneous (less weathered) zone of mixed, but generally higher, resistivity.

The time-lapse steps in Fig. B show a clear reduction in resistivity in the near-surface in step 1, indicating a wetting front following a rainfall event shown in the rainfall data in Fig. B. This front is heterogeneous, perhaps due to the lack of homogeneity in the subsurface. A second rainfall event before step 2 causes the wetting to be more pronounced.

The soil sensors in Fig. B corroborate this two-stage wetting, but only above 1m depth. This indicates more processing of the data may be required.

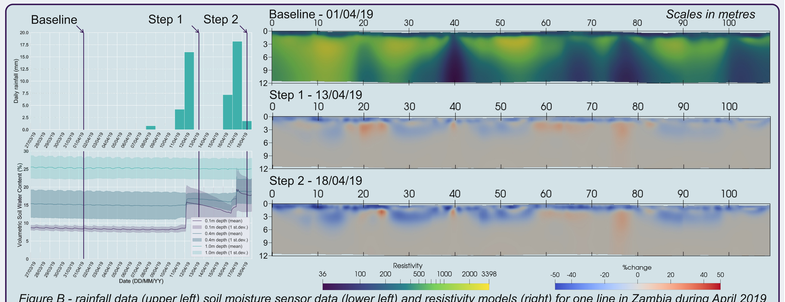


Figure B - rainfall data (upper left) soil moisture sensor data (lower left) and resistivity models (right) for one line in Zambia during April 2019

5 Malawi - shallow cross-borehole 3D ERT

Eight clusters of shallow boreholes have been installed in Malawi. There are 32 electrodes per cluster divided between 4 boreholes, which are spaced 1m apart, and reach a depth of 3.1m, as shown in Fig. C.

An example time-lapse inversion from one of the clusters is shown in Fig. D. The baseline model shows a resistive near-surface - interpreted as a dry layer - above a less resistive material. Step 1 of the timelapse shows no discernible change to the model, despite a small amount of rainfall (< 2mm).

Step 2 is modelled on data collected after a greater amount of rainfall (> 13mm), and shows a reduction in resistivity in the near surface that is visible as a clear wetting front, despite the apparent borehole based processing artefacts. Step 3 shows some drying in the near-surface, which has raised the resistivity from step 2, but in a non-uniform manner, showing preferential water retention in certain areas. Step 4 shows a new wetting front - caused by another period of rainfall - which has penetrated more deeply than that in step 2.

There is no point sensor data from the time-lapse period, but measurements currently being collected will have point sensor data checking ground truth.

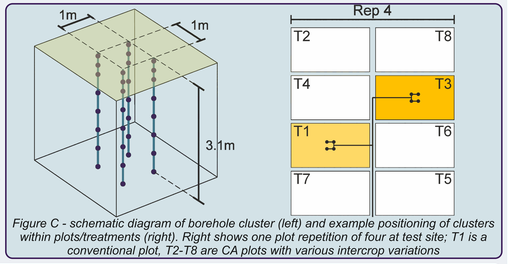


Figure C - schematic diagram of borehole cluster (left) and example positioning of clusters within plots/treatments (right). Right shows one plot repetition of four at test site; T1 is a conventional plot, T2-T8 are CA plots with various intercrop variations

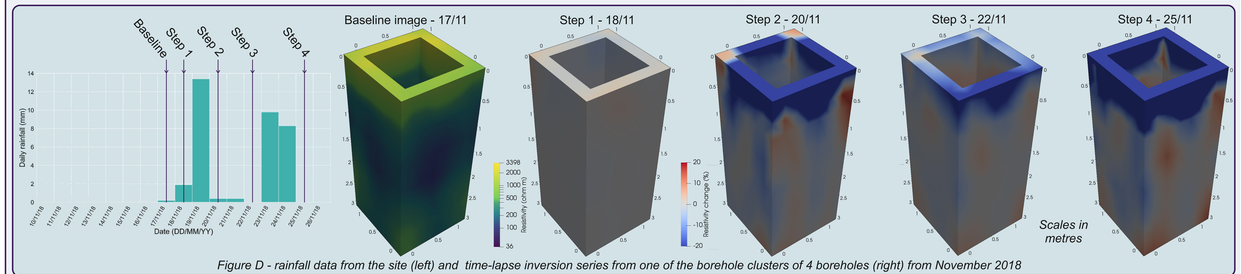


Figure D - rainfall data from the site (left) and time-lapse inversion series from one of the borehole clusters of 4 boreholes (right) from November 2018

6 Zimbabwe - 3D ERT from surface electrodes

Two arrays of 120 electrodes each have been installed in Zimbabwe, divided into 5 parallel lines of 24 electrodes as shown in Fig. E. This allows the resistivity modelling of a 3D volume beneath each array.

The initial models from the installation (one shown in Fig. F) shows a laterally homogenous subsurface, with a shallow layer of highly resistive material (dry, sandy soil) over less resistive material (damp soil), which correlates with what we found in excavations on site.

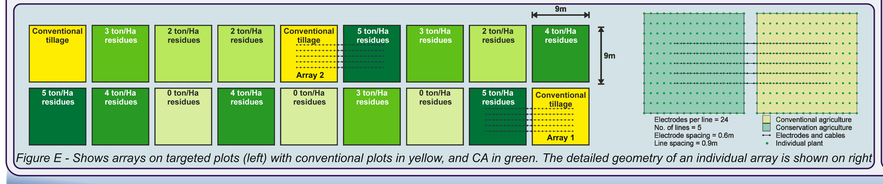


Figure E - Shows arrays on targeted plots (left) with conventional plots in yellow, and CA in green. The detailed geometry of an individual array is shown on right

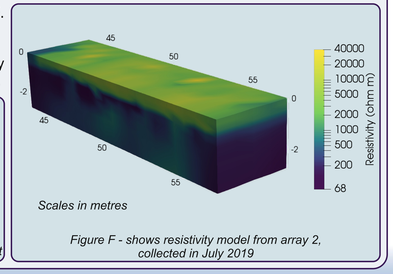


Figure F - shows resistivity model from array 2, collected in July 2019

7 Conclusions & next steps

The data presented in this poster is from the early stages of the project. It hasn't compared the hydrodynamics of the soils under conservation agriculture practices to those under conventional agricultural techniques. However, it demonstrates that ERT monitoring can be used in the setting of the study sites to model complex hydrodynamic patterns, and do so with a higher spatial resolution than can be done with point sensors alone. It also shows that the high temporal resolution, produced by the twice-daily data collection, is adept at modelling rapid changes in soil moisture.

Future work will involve fine tuning the time-lapse inversions, and combining the ERT datastream with data from the installed point sensors and hydrogeological monitoring programme of the CEPHaS project. This will enable the accurate modelling of the hydrodynamics under both CA and conventional agriculture, and will allow us to draw conclusions when comparing the two.

8 Acknowledgements

In addition to those institutions listed in the authorship, the authors would like to thank the International Maize and Wheat Improvement Center (CIMMYT), and Rothamsted Research (Richard Whalley and Andy Gregory in particular), for their collaboration and assistance with this research.

The GCRF-CEPHaS project is supported by UK Research and Innovation as part of the Global Challenges Research Fund, grant number NE/P02095X/1.

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