EVALUATION OF DC-BASED EQUIPMENT FOR APPARENT SOIL ELECTRICAL CONDUCTIVITY MEASUREMENT

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Abstract.

Apparent soil electrical conductivity (ECa) is a soil parameter used for precision agriculture applications where knowledge of the spatial variability of soil attributes is an important aspect to know. Researchers have concluded that ECa is powerful for spatial heterogeneity characterization of several physicochemical properties, identifying edaphic and anthropogenic factors that may influence crop yield, and provides a viable approach for delineating areas that behave similarly with respect to water flow and solute transport.

Soil ECa can be measured by direct and indirect methods, and the most common equipment is based on the "four-probe" direct method, such as Veris U3 (Veris®Technologies-EUA) and, more recently, Terran (FALKER-BR), both based on alternating electrical current. However, due to the lack of studies using such technology, especially in the northern region of Mato-Grosso state, researchers have been working on alternative equipment based on direct electrical current. Studies have been reported regarding the development of electronics, the equipment for continuous data collection, as well as equipment mapping performance when used in the field. However, a study comparing the developed DC-based method with a commercial system is still missing and therefore is the objective of the paper.

The study was conducted on a farm located in Tabaporã-MT, northern Mato Grosso, during October of 2021. Soil ECa mapping was accomplished using Veris U3 and the developed DC-based prototype throughout 112 ha field using two dedicated tractors so the data from both equipment could be collected simultaneously. One tractor was equipped with an RTK auto steering, and the other one had a light-bar guidance aid implemented in the software for DC-Based equipment and the machine paths were just offset of each other by the width of the

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implement so each one had no disturbed soil condition for data collection. The swath width was set up for 30 meters.

The generated filtered data maps were visually similar in terms of the spatial patterns, however with a difference in the range of the EC measurements, however, with a high coefficient of correlation. Therefore, a data normalization technique was applied to bring the DC-based data range to the same level as the commercial equipment. Moreover, a bivariate Moran's Index was conducted to establish the spatial correlation between the commercial and DC-based EC. Results were Moran's I of 0,83 and a p-value of 0.001, indicating that the DC equipment can be used as a valid tool to be used in educational research institutions and to continue leveraging precision agriculture research in northern Mato Grosso.

Keywords.
Soil Attributes, Spatial Variability, Precision Agriculture

INTRODUCTION

Apparent soil electrical conductivity (ECa) is one of the soil parameters used for precision agriculture applications where the knowledge of spatial variability of soil attributes is one important aspect to be known. Researchers have concluded that ECa is powerful for spatial heterogeneity characterization of several physico-chemical properties (CORWIN and Lesch 2005).

Soil ECa can be measured by direct and indirect methods, and the most common equipment is based on the “four-probe” direct method such as Veris 3100 (Veris®Technologies-EUA) (Molim and Castro 2006) based on alternated electrical current. Barbosa and Zandonadi (2017) mention several commercial ECa equipment while reporting research finds on development of low-cost instrumentation based on direct current for ECa measurements. The work was motivated by the lack of studies with ECa attribute in the northern region of Mato Grosso state. Meanwhile, an ECa equipment (TERRAM) was released by Falker (Precision agriculture equipment company located on southern of Brazil) in 2016.

With the promising results from Barbosa and Zandonadi (2017), Schwengber, *et al.* (2018) presented the first results of a dedicated implement for the DC based ECa readings on large scale fields of the northern Mato Grosso where 830 ha was mapped. In this study, the setup was evaluated regarding the data consistency and stability across different fields, considering that the implement was design based on coulters with limited rotation around the support axle. This characteristic was unique compared to commercial equipment, thus was designed to allow curves and turns without causing damages to the coulter bearings. Also, the coulter axle and hub needed to be specially machined to allow electrical continuity between coulter and the point in which the harness was connected. Further, Rosa *et al*. (2024) presented results regarding correlation coefficient between clay content and DC-based ECa of two fields studied in northern Mato Grosso with different clay content range where soil samples were taking on 2 ha regular grid. Correlation coefficient found for those studied fields was 0,81 and 0,95 for the 16,5% and 47,5% clay content range respectively. Result that follows the trend of many studies using commercial equipment such as (Sudduth, *et al*. (2005), Rodríguez-Pérez, *et al*. (2011) and Borba *et al*. (2015)).

Although, the presented results with the DC-based ECa device were promising, there was another type of evaluation missing to better validate the equipment, which was running a comparison with commercial equipment side by side. Therefore, the objective of this study was to accomplish a validation study with the DC-based ECa device using a commercial ECa equipment as a reference.

MATERIAL AND METHODS

The study was conducted on a farm located in Tabaporã-MT, northern of Mato-Grosso in October of 2021, during soybean planting season and minimum rain fall build up moisture in the fields for good ECa readings. The farm is in a region of “latossolo vermelho-amarelo”, according to the IBGE 2026, and the chosen field had a substantial texture variability going from 20 up to 60% clay content.

The farm grows soybean as full season crop and may have multiple crops planted as second crop such, as corn, rice and some type of cover crops depending mostly on the market opportunity and soil health. In the chosen field, happened to have rice as a second crop in the season, so the data was collected on top of rice stover before new soybean crop was planted.

Soil ECa mapping was accomplished using Veris U3 and the developed DC-based device throughout a 112 ha field using two dedicated tractors so the data from both equipment could be collected simultaneously. One tractor was equipped with RTK autosteering and the other one had a light bar guidance aid implemented in the software for DC-Based equipment (Figure 1).

The tractor paths were just offset by the width of the implement, so each one had no disturbed soil condition for data collection. The swath width was set up for 30 meters and each equipment was set to register data at 1Hz, and ground speed was set to 10 km.h^{-1} so similar amounts of data points were collected in both equipment.

Figure 1: Detail of ECa mapping device VERIS U3 (A) and both EC riggs being tested, VERIS3100 in the front and DC-based prototype in the back of the picture (B).

Data extract from equipment's console was imported into computer and processed using MATLAB (2024b) for map visualization, data filtering (Equation 1) and normalization (Equation 2), while spatial correlation analysis was accomplished by a bivariate Moran's Index using GeoDa, running the spatial permutation approach for Index test of significance (Anselin L. 2024). The workflow of the data analysis is presented on **Error! Reference source not found.**

$$EC_f = \text{average}(EC) \pm 2.5 * SD(EC) \tag{1}$$

where EC_f =filtered EC (ms.m^{-1}), *SD* = Standard Deviation

$$EC_{nor} = \frac{(EC - \min(EC) * (\max(EC_{ref}) - \min(EC_{ref})}{\max(EC) - \min(EC)} + \min(EC_{ref}) \tag{2}$$

where EC_{nor} =the normalized EC (ms.m^{-1}), *EC*=reading for DC-device(ms.m^{-1}), EC_{ref} = EC reading from EC 3100(ms.m^{-1}).

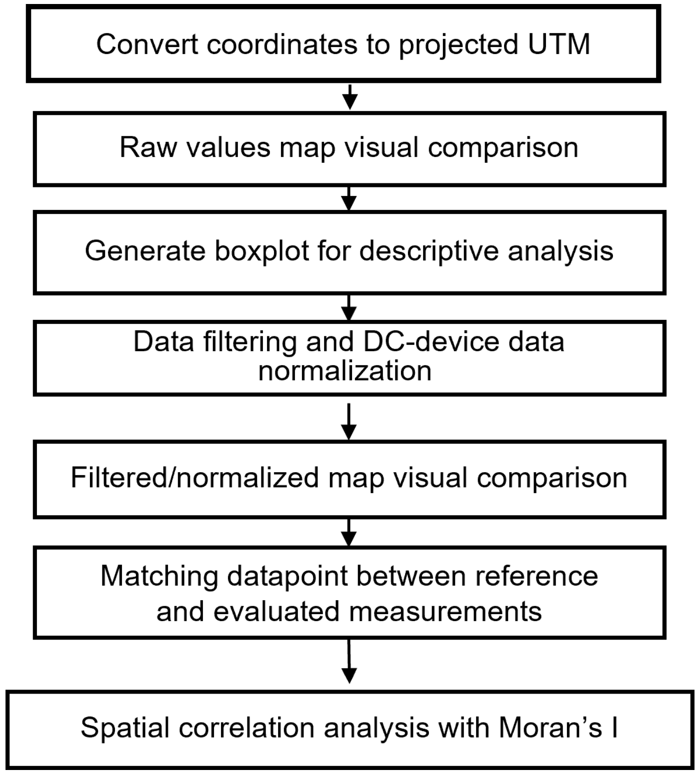

Figure 2: Flow chart of the steps taken during data processing and analyses

After data filtering and normalization was accomplished and datapoint matching algorithm was carried out to compute spatial-correlation analyses. For each coordinate registered on the Veris filtered data set, it was found the closest coordinate from the DC-based device. Therefore, the same number of EC readings were the same for both equipment.

RESULTS AND DISCUSSIONS

Maps with raw data from both equipment are presented on Figure 3 where is possible to notice the similarity regarding ECa spatial pattern presented by the evaluated equipment. The descriptive evaluation using boxplot (Figure 4(A)) indicated some outliers readings (red cross above whiskers) in both equipment which were discarded after applying the statistical filter as described in Equation 1. Note that, although spatial patterns are similar, a significant difference exists regarding reading range and therefore, the range between 25th and 75th percentiles.

Due to the fact that both equipment were traversing the field on very close passes, therefore, subject to same field variability, the data normalization (Equation 2), could be applied and the result is presented on Figure 4 (B) as well as the maps after filtering, normalization and datapoint matching (Figure 5). Note that the spatial pattern did not change as normalization was applied.

Finaly, the bivariate Moran's I scatter plot is presented on Figure 6 indicating the strong autocorrelation between the DC-based ECa and VERIS ECa resulting in an Index value of 0,83 using a k-Nearest neighbors Weight matrix. The pseudo p-value result for a 999-permutation test was 0.001 indicating the DC-based ECa was significant and strongly correlated with VERIS ECa in space and therefore capable of represent same spatial ECa pattern and the reference equipment.

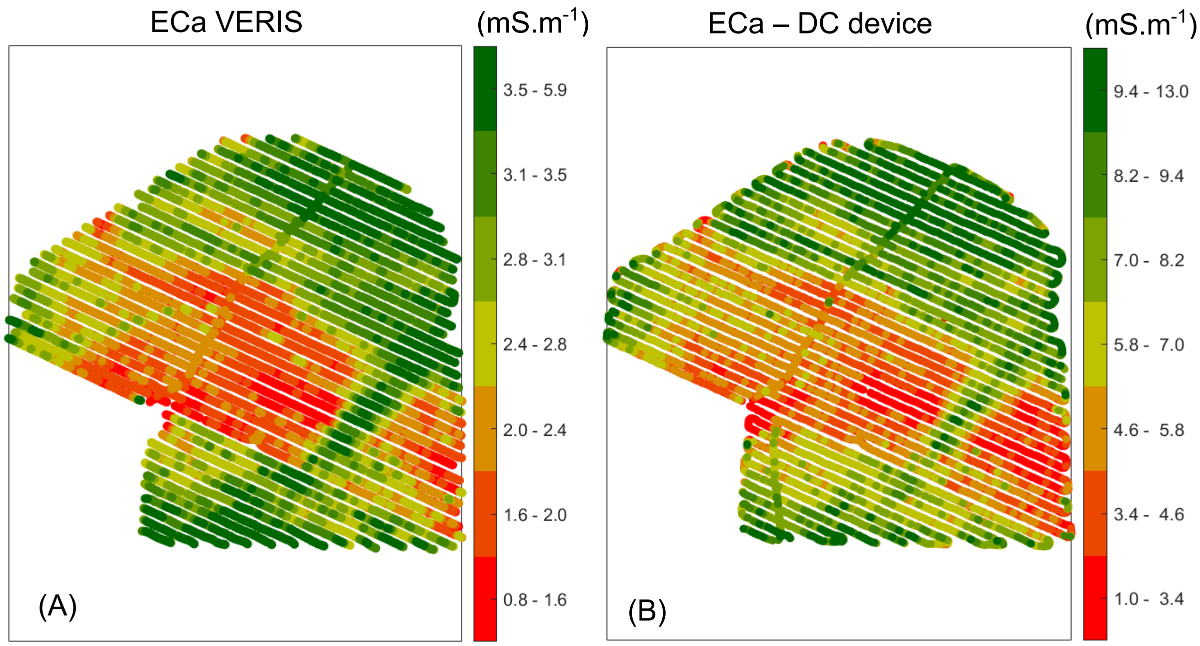

Figure 3: Resulting maps before data filtering and normalization for VERIS U3 (A), and DC based device (B)

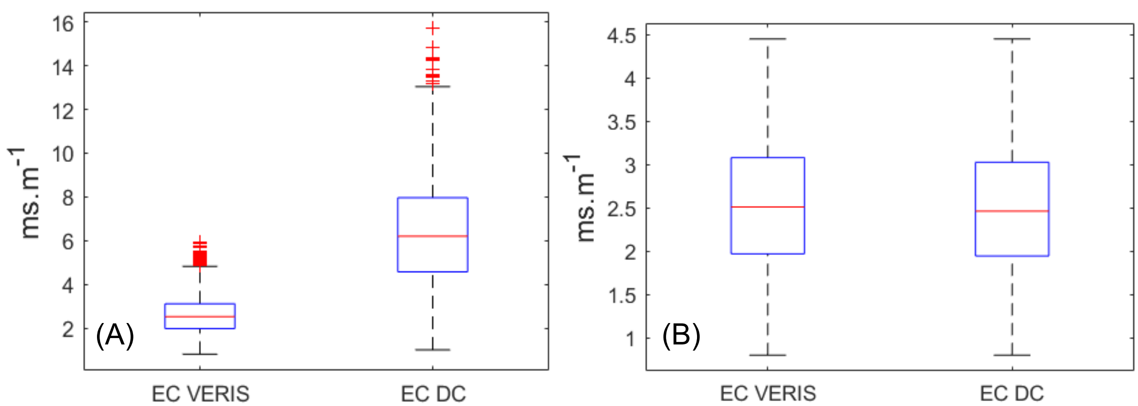

Figure 4: Boxplot graphs representing data before (A) and after (B) data filtering and normalization for the evaluated equipment (VERIS U3 and DC-based device)

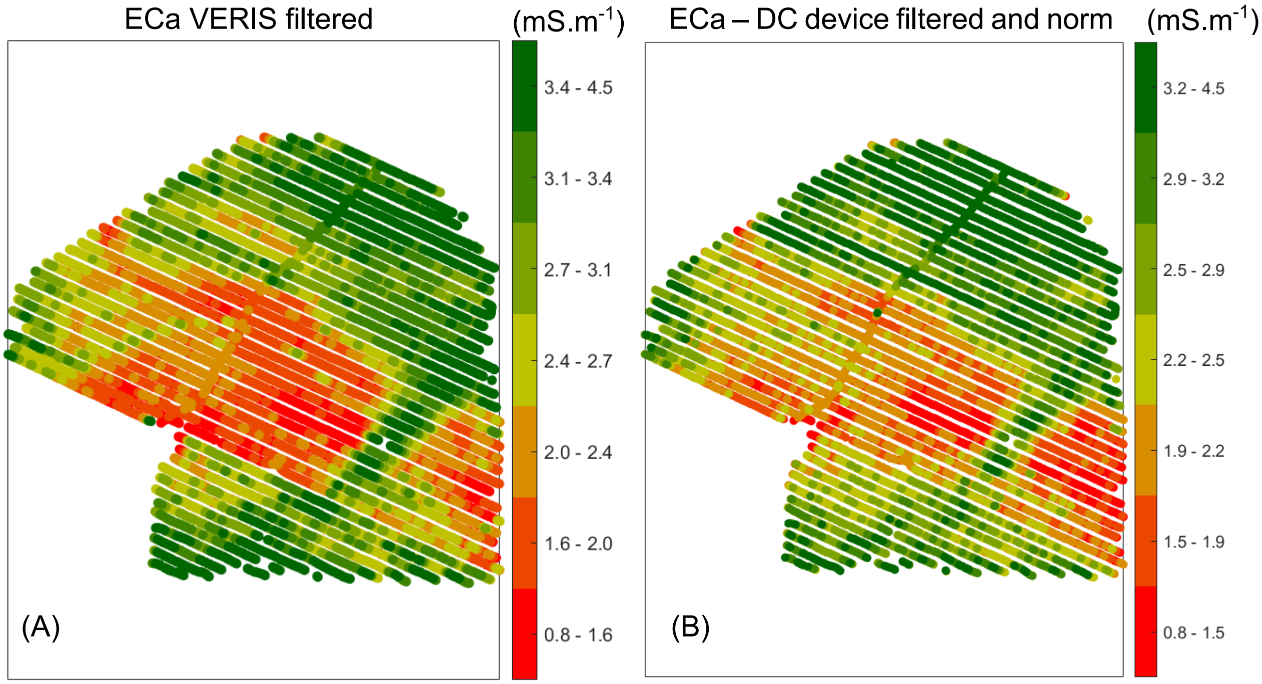

Figure 5: Resulting maps after data filtering, normalized and datapoint match for VERIS U3(A), and DC based device (B)

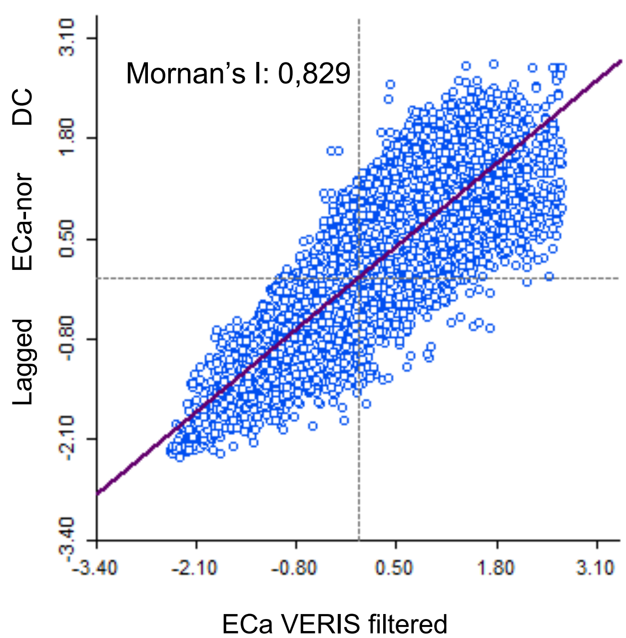

Figure 6: Bivariate Moran's I scatter plot for autocorrelation analysis between VERIS U3 and DC-device ECa readings;

Conclusion:

It was concluded that, in the studied case, the DC-based ECa measurement equipment was capable of represent similar ECa spatial patterns as the reference commercial equipment, thus completing a reasonable validation process considering the results presented on previous studies.

Therefore, the DC-based equipment can be used as valid tool to be used in educational research institutions and continue leveraging precision agriculture research in northern Mato Grosso.

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References

Anselin L. (2024a). An Introduction to Spatial Data Science with GeoDa. Volume 1: Exploring Spatial Data. CRC/Chapman&Hall, Boca Raton, FL.

Barbosa, F. S. & Zandonadi, R. S. (2017) Low cost aparatus for aparent soil electrical conductivity measurment based on direct currente. NATIVA, v. 5, p. 37.

Borba, M. Z. De., Freddi, O. Da S., Trevisan, R. G., Molin, L. P. (2015) Condutividade elétrica aparente no mapeamento da textura do solo. In: XXXV Congresso Brasileiro de Ciência do Solo, Natal.

Corwin, D.L., & Lesch, S.M., (2005) Apparent soil electrical conductivity measurements in agriculture. Computers and Electronics in Agriculture, 46, 11-43.

IBGE – INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. (2026) BDiA WEB - Banco de Dados de Informações Ambientais: pedologia. Disponível em: https://bdiaweb.ibge.gov.br/#/consulta/pedologia. Acesso em: 6 jun. 2026.

Molin, J. P.; Castro, C. N.; Condutividade elétrica -Aliada potencial. (2006) Cultivar Máquinas, Pelotas, 8-11.

Rosa, S. C. ; Peres, E. H. A. ; Zandonadi, R. S. (2024).Avaliação de um implemento para mensuração de condutividade eletrica aparente do solo utilizando instrumentação com base em corrente contínua. In: ConBAP - Congresso Brasileiro de Agricultura de Precisão e Digital 2024, Ribeirão Preto. ConBAP - Congresso Brasileiro de Agricultura de Precisão e Digital 2024 – ANAIS v. 1.

Rodríguez-Pérez, J.R., Plant, R.E., Lambert, JJ., Smart, D. R. (2011) Using apparent soil electrical conductivity (ECa) to characterize vineyard soils of high clay content. Precision Agric 12, 775–794 . https://doi.org/10.1007/s11119-011-9220-y

Schwengber, D., Koelln, F. H. B., Turcatto, L. M., Zandonadi, R. S. (2018).Implemento de baixo custo para mensuração de condutividade elétrica aparente do solo. In: 1° simpósio mato-grossense de mecanização agrícola e agricultura de precisão. SIMAP, 2018, Sinop.

Seifi, M.R., Alimardani, R., Sharifi, A. (2010). Design and Development of a Portable Soil Electrical Conductivity Detector. Asian Journal of Agricultural Sciences 2, 168-173.

(DesignandDevelopmentofaPortableSoilElectricalConductivityDetector.pdf)

Sudduth, K.A., Kitchen, N. R., Wiebold, W. J., Batchelor, W. D., Bollero, G. A., Bullock, D. G., Clay, D. E., Palm, H. L., Piercef, F. J., Schuler, R. T., Thelen, K. D. (2005) Relating apparent electrical conductivity to soil properties across the north-central USA. Computers and Electronics in Agriculture, New York, v.46, p.263-283, 2005.

The Mathworks Inc. MATLAB Version: 24.2.0.2740171 (R2024b).(2024) Natick: The MathWorks Inc.