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SPATIAL DISTRIBUTION OF VISUAL SOIL STRUCTURE EVALUATION IN A COFFEE PRODUCTION AREA

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Abstract

Visual assessment of soil structure can be a valuable tool for monitoring soil physical condition under different management systems, particularly when integrated with precision agriculture to support decision-making. This study aimed to evaluate the soil structure of a coffee-cropped area using the Visual Evaluation of Soil Structure (VESS) method and to analyze its spatial distribution in association with soil moisture and electrical conductivity maps. The 2.4 ha field was subdivided into a regular sampling grid with 30 sampling points; undisturbed soil samples were collected at 15 points from the 0-25 cm layer for VESS assessment, following the method's scoring guidelines. Structural quality scores (Qe) ranged from 1 to 5, where 1 indicates very good structural condition and 5 indicates poor condition. In addition, soil moisture and electrical conductivity were measured at all 30 points using an electronic sensor. Spatial interpolation was performed using the Inverse Distance Weighting (IDW) method in a Geographic Information System (GIS) environment (QGIS). The mean VESS score remained within the 1-2 range, indicating no need for soil management intervention. The combined interpretation of VESS, moisture, and electrical conductivity data was effective for characterizing soil structural condition, as evidenced by similarities among the generated maps, demonstrating potential for mapping soil spatial variability. Moreover, soil moisture was found to directly influence visual structural assessment.

Keywords: *Soil structure; Spatial variability; Electrical conductivity.*

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1 INTRODUCTION

Coffee production in Brazil has very significant numbers for the world, with an area of 1.82 million hectares in 2021, producing a total of approximately 48.8 million 60 kg bags, which generates a revenue of 743 billion reais and represents 30% of world production, placing Brazil in 1st place in this regard in the world (EMBRAPA, 2021). However, there are a number of external or internal factors that can influence crop production. Among them, the soil and its structure need to be of good quality to provide a suitable environment for plant development; inadequate management can cause problems such as erosion or compaction (CARVALHO et al., 2013).

In this sense, farmers have been seeking technological alternatives that contribute to improving the management and production of their crops, and precision agriculture (PA) appears as a great tool. PA allows the creation of various types of maps that contribute to understanding the variability found in the crop and to more efficiently applying inputs. However, some of this information is difficult to obtain or is costly, such as laboratory soil analysis. Therefore, soil analysis tools that are applicable and low-cost are very welcome.

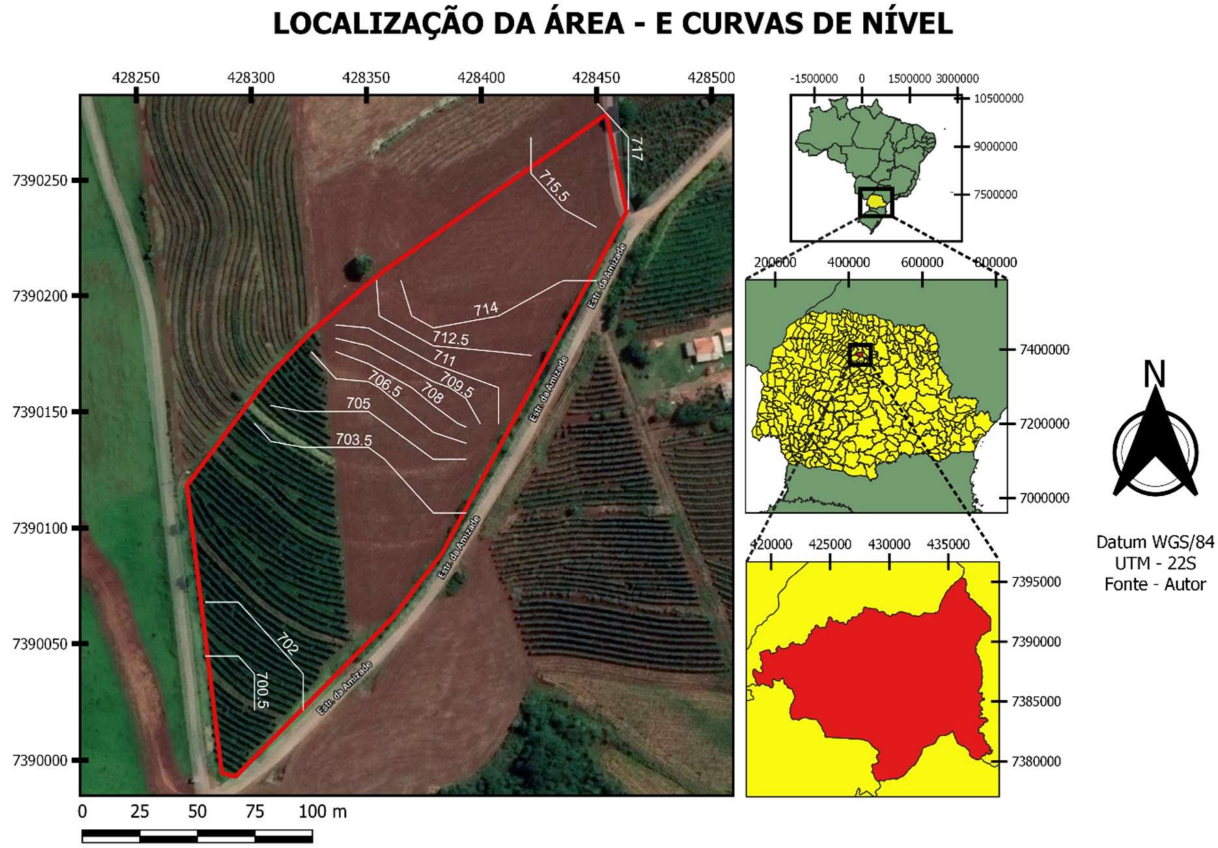
In this context, the method called Visual Evaluation of Soil Structure – VESS, proposed by Ball et al. (2007), meets this need. VESS is a visual assessment of the soil through the collection of undisturbed samples. Thus, this study aimed to apply the Visual Evaluation of Soil Structure (VESS) methodology to an area cultivated with coffee. Specifically, the work sought to analyze the existing spatial variability through data interpolation (IDW method in QGIS) and correlate the structural quality of the soil with the variables of moisture and electrical conductivity of the same.

2 MATERIALS AND METHODS

2.1 STUDY AREA

The study was conducted at the Santo Antônio site, located in the municipality of Jandaia do Sul - PR, Brazil, at coordinates 23°35'33" S and 51°42'07.8" W. The climate, according to the Köppen classification, is Cfa (subtropical climate with hot summers). Data were collected in 2018 in an area of 2.4 ha cultivated with IPR 100 coffee cultivar since 2013, on clayey Latosol soil with conventional treatments.

Figure 1 - Location and Contour Lines



SOURCE: ADAPTED FROM THE AUTHOR (2021).

2.2 SOIL SAMPLING AND DATA COLLECTION

The sampling grid consisted of 30 georeferenced points using a GNSS receiver (Leica GS15), predefined in a regular grid and always sampled between the rows of the coffee crop.

Moisture and Electrical Conductivity: All 30 points were sampled using an electronic sensor (CS658, Campbell Scientific) equipped with a 20 cm probe, in order to obtain direct information on moisture (%) and apparent electrical conductivity (EC). VESS Assessment: In 15 of the 30 points, sampling was carried out using the VESS visual analysis method according to the recommendations of Ball et al. (2007).

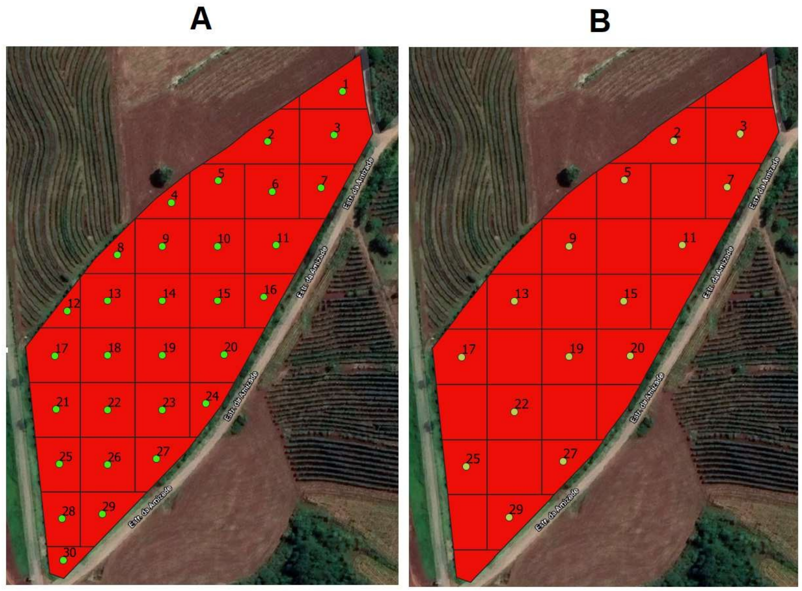
Figure 2 - GNSS (LEICA GS15)

SOURCE: LEICA GEOSYSTEMS.

Figure 3 - SENSOR (CS658, CAMPBELL)

SOURCE: CAMPBELL SCIENTIFIC.

Figure 4 - A) Moisture and Electrical Conductivity (EC) Points. B) Visual Analysis Points (VESS).



SOURCE: ADAPTED FROM THE AUTHOR (2021).

2.3 VISUAL EVALUATION OF SOIL STRUCTURE (VESS)

The VESS procedure consisted of extracting an undisturbed block-shaped soil slice (approx. 20 cm wide x 22-25 cm deep) using a straight shovel. The blocks were carefully handled and fragmented along their natural cracks to identify the layers and aggregates.

Each identified layer received a score (Qe) ranging from 1 (very good structural condition, highly porous aggregates) to 5 (very poor condition, massive structure and hard clods) according to the chart by Ball et al. (2007). The Total Score for the point was calculated by weighting the score of each layer by its thickness.

Figure 5 - Extraction of a soil block in an area under pasture.

SOURCE: PENNING (2015).

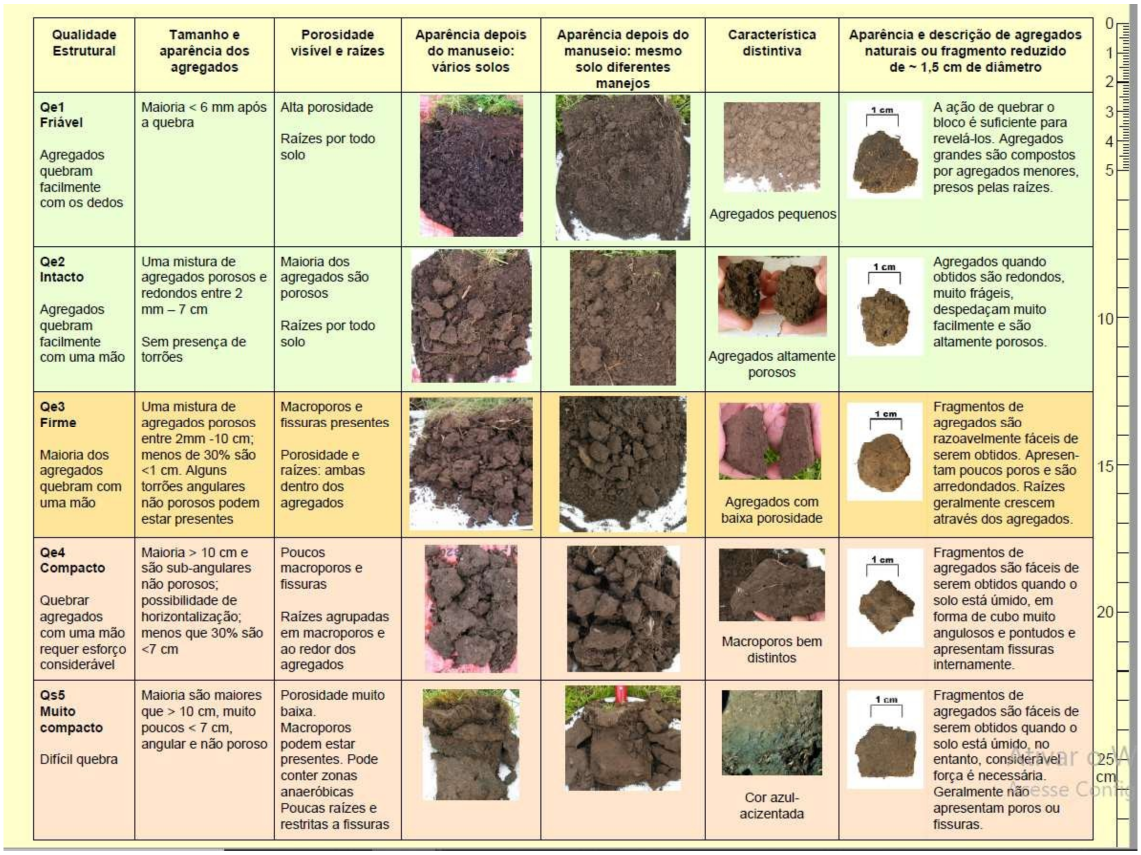
Figure 6 - EXTRACTION OF A BLOCK OF FIRM SOIL.

SOURCE: BALL ET AL. (2007).

Figure 7 - A slice of soil being broken up to assess aggregation.

SOURCE: PENNING (2015).

Figure 8 - ASSESSMENT LETTER FROM BALL ET AL. (2007).



Qualidade Estrutural	Tamanho e aparência dos agregados	Porosidade visível e raízes	Aparência depois do manuseio: vários solos	Aparência depois do manuseio: mesmo solo diferentes manejos	Característica distintiva	Aparência e descrição de agregados naturais ou fragmento reduzido de ~ 1,5 cm de diâmetro
Qe1 Friável Agregados quebram facilmente com os dedos	Maioria < 6 mm após a quebra	Alta porosidade Raízes por todo solo			Agregados pequenos	1 cm A ação de quebrar o bloco é suficiente para revelá-los. Agregados grandes são compostos por agregados menores, presos pelas raízes.
Qe2 Intacto Agregados quebram facilmente com uma mão	Uma mistura de agregados porosos e redondos entre 2 mm – 7 cm Sem presença de torrões	Maioria dos agregados são porosos Raízes por todo solo			Agregados altamente porosos	1 cm Agregados quando obtidos são redondos, muito frágeis, despedaçam muito facilmente e são altamente porosos.
Qe3 Firme Maioria dos agregados quebram com uma mão	Uma mistura de agregados porosos entre 2mm -10 cm; menos de 30% são <1 cm. Alguns torrões angulares não porosos podem estar presentes	Macroporos e fissuras presentes Porosidade e raízes: ambas dentro dos agregados			Agregados com baixa porosidade	1 cm Fragmentos de agregados são razoavelmente fáceis de serem obtidos. Apresen-tam poucos poros e são arredondados. Raízes geralmente crescem através dos agregados.
Qe4 Compacto Quebrar agregados com uma mão requer esforço considerável	Maioria > 10 cm e são sub-angulares não porosos; possibilidade de horizontalização; menos que 30% são <7 cm	Poucos macroporos e fissuras Raízes agrupadas em macroporos e ao redor dos agregados			Macroporos bem distintos	1 cm Fragmentos de agregados são fáceis de serem obtidos quando o solo está úmido, em forma de cubo muito angulosos e pontudos e apresentam fissuras internamente.
Qs5 Muito compacto Difícil quebra	Maioria são maiores que > 10 cm, muito poucos < 7 cm, angular e não poroso	Porosidade muito baixa. Macroporos podem estar presentes. Pode conter zonas anaeróbicas Poucas raízes e restritas a fissuras			Cor azul-acizentada	1 cm Fragmentos de agregados são fáceis de serem obtidos quando o solo está úmido, no entanto, considerável força é necessária. Geralmente não apresentam poros ou fissuras.

SOURCE: BALL ET AL. (2007).

2.4 SPATIAL ANALYSIS AND INTERPOLATION

The VESS Score, Moisture, and EC data were processed using the QGIS Geographic Information System (GIS) software. The Inverse Distance Weighting (IDW) deterministic interpolation method was used to create thematic maps of spatial variability, allowing for visual correlation between structural quality, moisture retention, and electrical conductivity of the soil in the study area.

3 RESULTS AND DISCUSSION

3.1 HUMIDITY AND ELECTRICAL CONDUCTIVITY

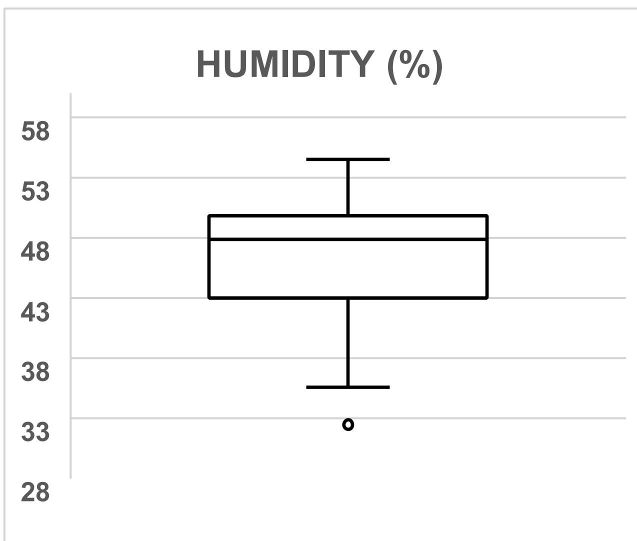
The collected data demonstrated that the variables presented similar behaviors at the same spatial points. Humidity showed a variation of 11.7% in the area, while EC varied approximately 10.3%.

TABLE 1 - MOISTURE AND EC DATA

PONTO	UMIDADE (%)	C.E (dS/m)	PONTO	UMIDADE (%)	C.E (dS/m)	PONTO	UMIDADE (%)	C.E (dS/m)
1	39,3	0,632	**11**	39,9	0,639	**21**	49,8	0,774
2	35,6	0,591	**12**	43,6	0,688	**22**	48,8	0,76
3	36,6	0,6	**13**	50,2	0,786	**23**	49,6	0,77
4	45,3	0,708	**14**	46,4	0,723	**24**	49,3	0,78
5	32,5	0,551	**15**	48,6	0,756	**25**	45,6	0,713
6	50	0,777	**16**	45,2	0,702	**26**	41,5	0,659
7	53,2	0,839	**17**	52	0,812	**27**	54,5	0,858
8	47,9	0,751	**18**	51,8	0,817	**28**	49,8	0,768
9	39	0,63	**19**	49,9	0,774	**29**	47,9	0,748
10	43,5	0,683	**20**	47,8	0,742	**30**	46,4	0,726

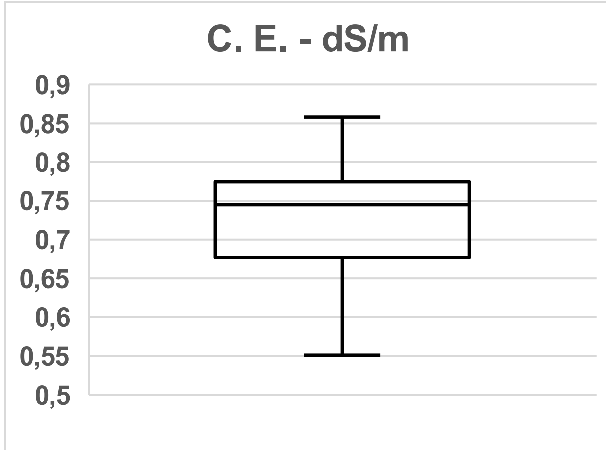
SOURCE: ADAPTED FROM THE AUTHOR (2021).

CHART 1 – HUMIDITY BOXPLOT



SOURCE: ADAPTED FROM THE AUTHOR (2021).

GRAPH 2 - ELECTRICAL CONDUCTIVITY (EC)



SOURCE: ADAPTED FROM THE AUTHOR (2021).

Spatial mapping using IDW confirmed the existing dependence between EC and moisture, demonstrating the great potential that EC measurement has to assist in obtaining data for physical characterization in a fast way. The moisture map also revealed a clear division in the area (a more humid portion and another less so), which is related to the direction of runoff and slope of the terrain (higher elevation at point 1, lower elevation at point 30).

3.2 STRUCTURAL QUALITY (VESS METHOD)

The VESS assessment resulted in scores whose mean (1.64) and median (1.59) are in the range of 1-2, indicating that the soil has "Good" structural quality, in which aggregates are porous, roots do not present growth restrictions, and manipulation of clods reveals ease of breakage. Therefore, corrective mechanical management interventions (such as subsoiling) are not necessary in the short or long term.

TABLE 2 - VESS. DATA

PONTO	CAMADA TOTAL (cm)	N° CAMADA	TAMANHO (cm)	Qe	ESCORE	ESCORE TOTAL
2	25	1	5	1	0,2000	1,5400
		2	7	2	0,5600	
		3	13	1,5	0,7800	
3	**22**	**1**	**6**	**1,5**	**0,4091**	**2,2273**

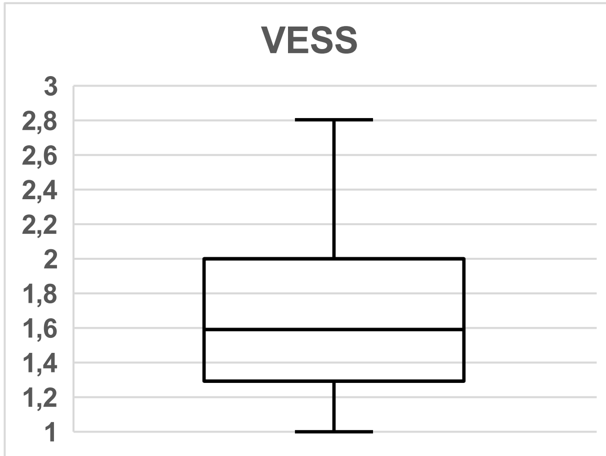
		2	6	2,5	0,6818	
		3	10	2,5	1,1364	
7	20	1	9	1	0,4500	2,1000
		2	11	3	1,6500	
5	21	1	7	1	0,3333	2,0000
		2	14	2,5	1,6667	
9	21	1	8	1	0,3810	1,6190
		2	13	2	1,2381	
11	20	1	7	1	0,3500	1,3250
		2	13	1,5	0,9750	

PONTO	CAMADA TOTAL (cm)	N° CAMADA	TAMANHO (cm)	Qe	ESCORE	ESCORE TOTAL
15	22	1	9	1	0,4091	1,5909
		2	13	2	1,1818	
13	24	1	10	1	0,4167	1,2917
		2	14	1,5	0,8750	
17	20	1	9	1	0,4500	1,2750
		2	11	1,5	0,8250	
19	22	1	7	1,5	0,4773	1,8409
		2	15	2	1,3636	
20	21	1	9	1	0,4286	1,0000
		2	12	1	0,5714	
22	22	1	12	1,5	0,8182	1,7273
		2	10	2	0,9091	
27	22	1	10	1	0,4545	1,0000
		2	12	1	0,5455	
25	23	1	15	1	0,6522	1,3478
		2	8	2	0,6957	
29	23	1	9	2,5	0,9783	2,8043

2	14	3	**1,8261**

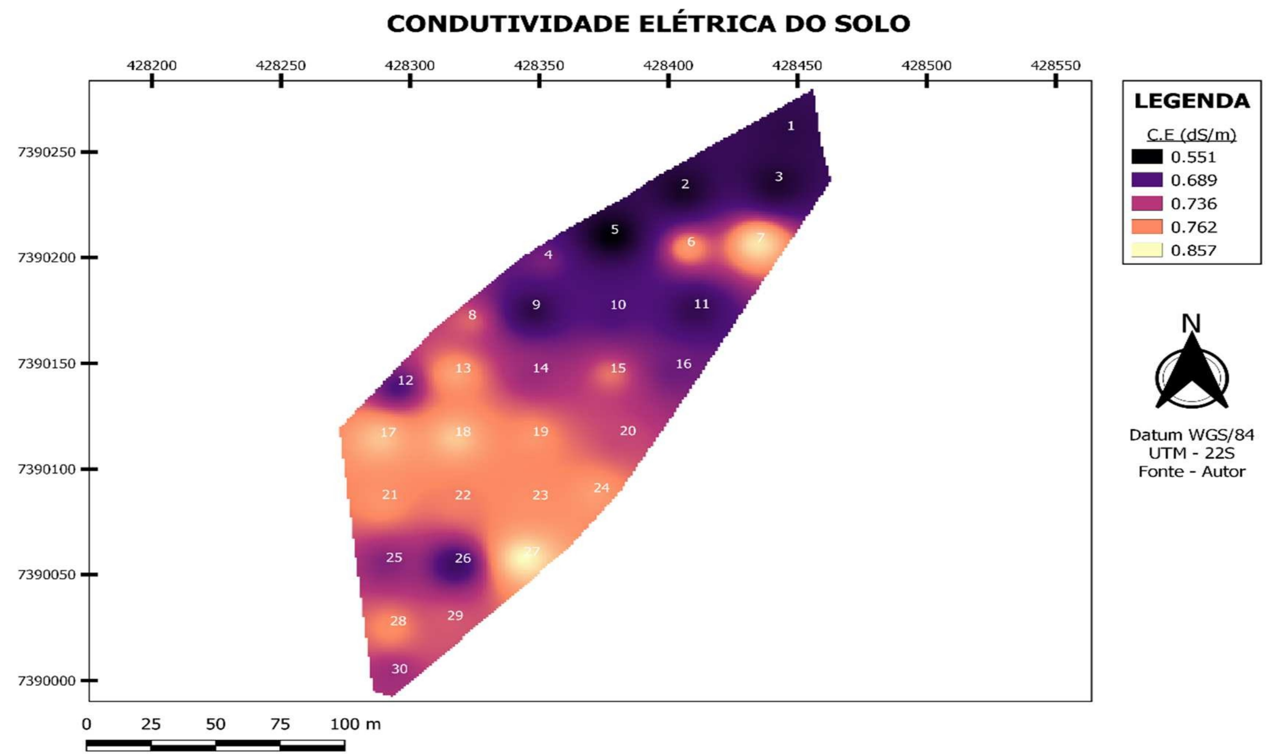
SOURCE: ADAPTED FROM THE AUTHOR (2021).

GRAPH 3 – BOXPLOT VESS METHOD



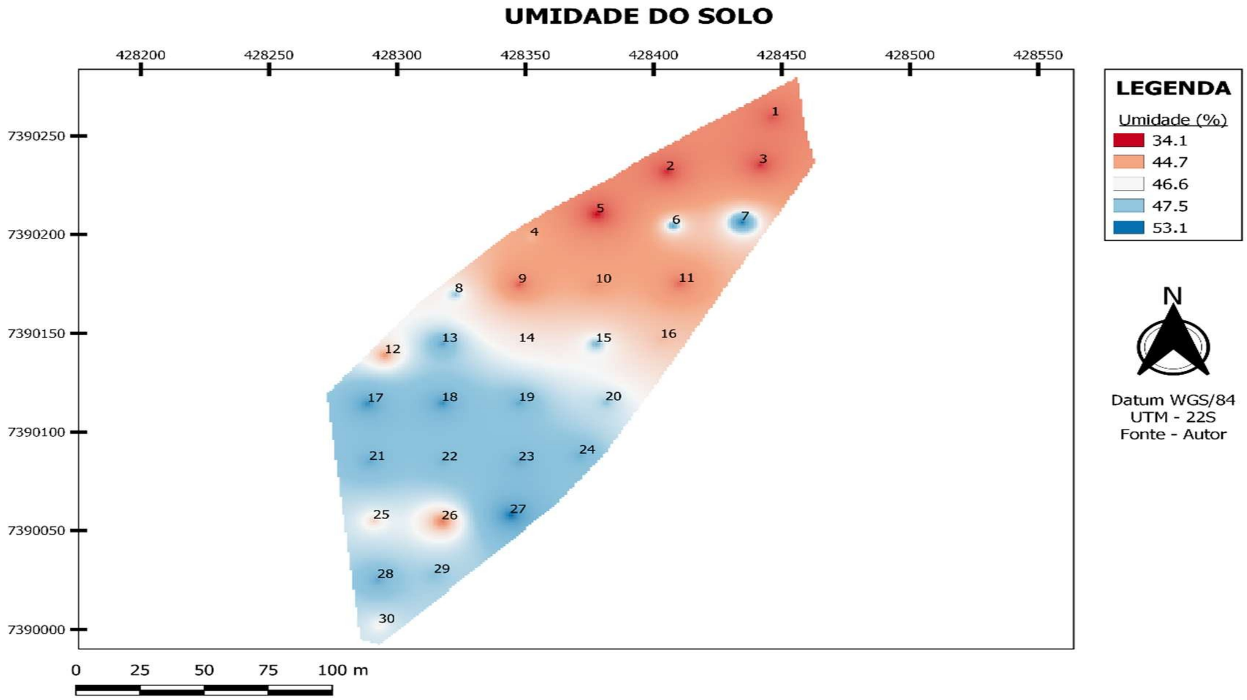
SOURCE: ADAPTED FROM THE AUTHOR (2021).

Figure 9 – ELECTRICAL CONDUCTIVITY MAP.



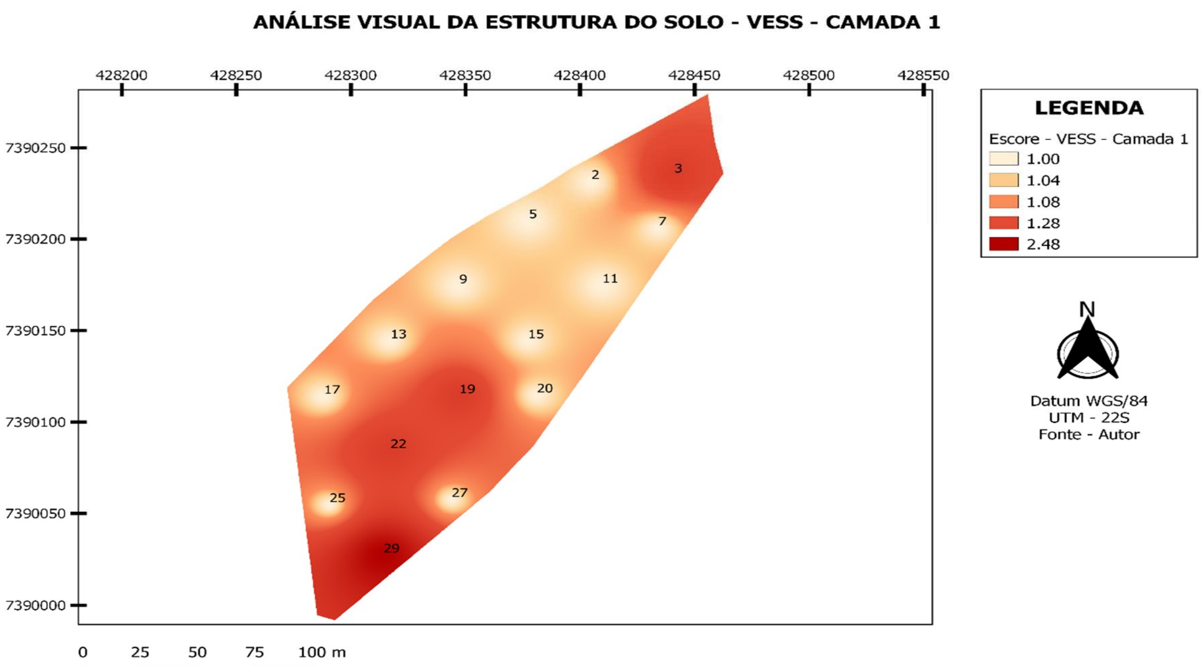
SOURCE: ADAPTED FROM THE AUTHOR (2021).

Figure 10 – HUMIDITY MAP



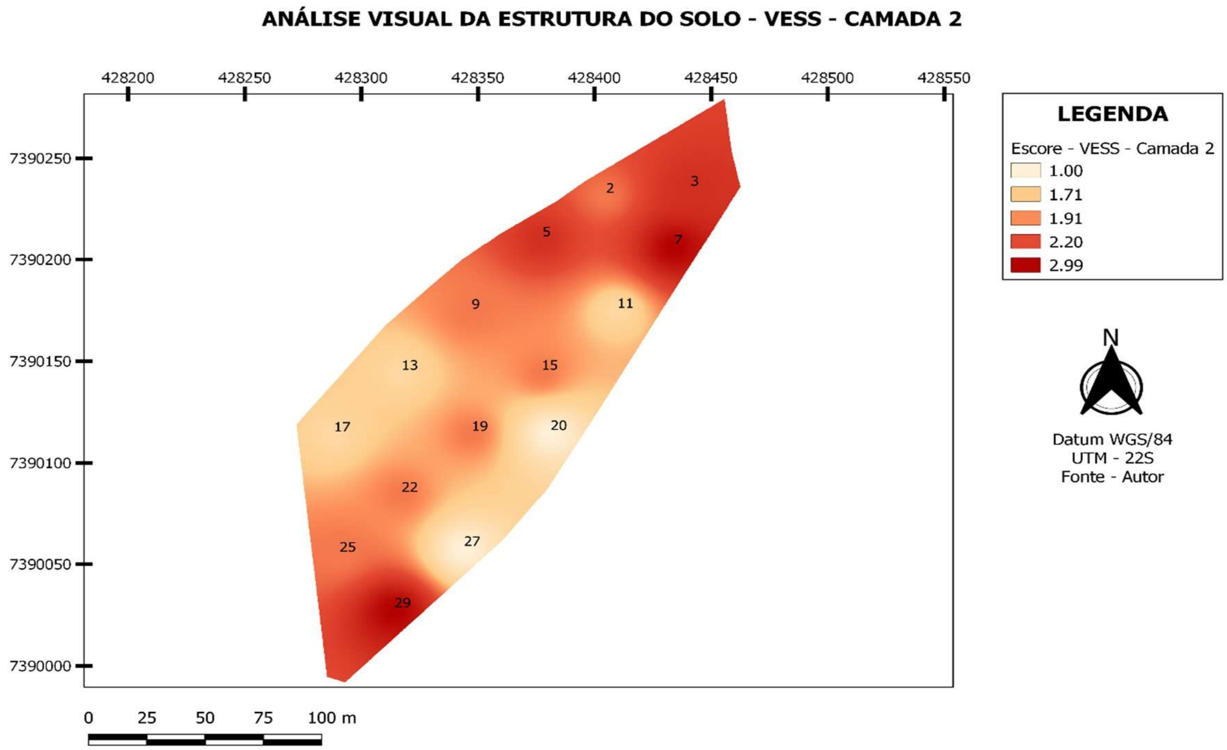
SOURCE: ADAPTED FROM THE AUTHOR (2021).

Figure 11 - VISUAL ANALYSIS OF SOIL STRUCTURE - VESS - LAYER 1



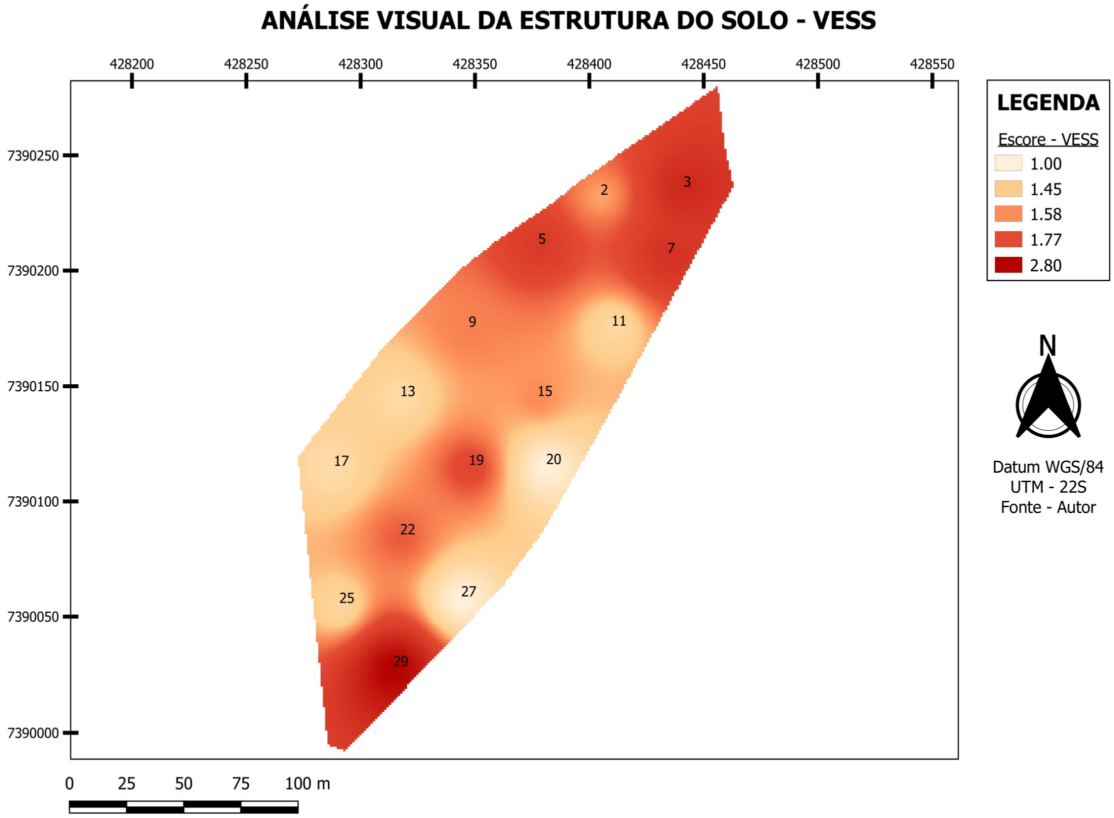
SOURCE: ADAPTED FROM THE AUTHOR (2021).

Figure 12 - Visual Analysis of Soil Structure - VESS - Layer 2



SOURCE: ADAPTED FROM THE AUTHOR (2021).

Figure 13- MAP VESS.



SOURCE: ADAPTED FROM THE AUTHOR (2021).

The relationship between moisture content and assessment scores proved to be inversely proportional. As the moisture content increased, the visual assessment degradation score tended to decrease (indicating better structure). This highlights the importance of friable conditions (adequate moisture) for performing the VESS method, avoiding distortions caused by excessively dry or plastic soil (Schiebelbein et al., 2019).

4 CONCLUSIONS

Visual assessment using the VESS method was efficient in characterizing the structural characteristics of the soil cultivated with coffee, showing a "Good" physical condition (scores between 1 and 2), with no current need for corrective mechanical interventions.

Agreement and a direct relationship were observed between the spatial maps of moisture and electrical conductivity, confirming the robustness of these variables in the rapid indirect characterization of soil physical conditions.

The integrated application of VESS and electronic sensors in IDW mapping represented a practical and low-cost alternative for understanding spatial variability, strengthening decision-making in precision coffee farming.

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