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Assessment and mapping of soil calcium carbonate content using electromagnetic induction sensor

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Abstract

The aim of this study was to investigate the possibility of predicting CaCO3 content through Electromagnetic conductivity (EM) on cultivated soils. Soils were sampled at 30 locations within the study area. The EM was measured using a mobile electromagnetic induction (EM38) sensor. Relations between CaCO3 and EM were analyzed with linear regression and geostatistical analysis. Further research is needed to fully evaluate the potential of EM measurements for predicting CaCO3 in tilled soil. The results also show a strong correlation between EM, and CaCO3% (R2 > 0.9). The Wilcoxon test shows a non-significant difference between measured CaCO3 and those predicted by ECa (p > 0.05). This result confirms the EMI technique as a useful tool to evaluate the spatial variability of soil CaCO3. All of these results suggest that the EM represents a real possibility for reducing the number of soil samplings, by guaranteeing the reliability of the estimates of real values of CaCO3 and their surface spatial distribution. ECa could therefore be a useful tool to spatialize and predict the distribution of CaCO3 in soil cultivated.

Keywords: Soil calcium carbonate, Electromagnetic Induction, Corso district, Algeria

Introduction

Soil calcium carbonate (CaCO3) content is a crucial factor in determining soil fertility and can significantly impact agricultural productivity (Doner and Lynn, 1989; McBride, 1979 ; Marion et al., 1994 ;Oyanarte et al., 1994 ; Umer et al., 2020 and Shan et al., 2021)

The presence of calcium carbonate in soil has implications for soil properties and fertility. It can affect soil structure, nutrient availability, and pH levels (Loeppert, 1986; Bui et al.,1990;Sarmadian, 2010 ; Shan et al., 2021 ; Xu et al., 2022and Nandkishor, 2023).

Overall, perception and predicting soil CaCO3 content are essential components of sustainable soil management (Nandkishor, 2023).This is not without effect on cartography and land use.

Indeed, study of the distribution and dynamics of calcium carbonate in soils is important for various reasons, including agricultural management, land use planning (Kassim, 2013and Al-Ghanimi, 2023).

Understanding the role of calcium carbonate in soil is crucial for effective soil management and agriculture practices. It helps farmers and researchers make informed decisions about soil amendments, fertilization, and pH adjustments to optimize plant growth and productivity(Doner and Lynn, 1989; McBride, 1979;Loeppert, 1986and Al-Ghanimi, 2023).

To predict soil CaCO3 content, various methods can be employed, including laboratory analysis, remote sensing, and geospatial modelling. These methods often involve the assessment of soil samples, but advancements in technology have allowed for more efficient and accurate predictions at larger scales(U.S. Salinity Laboratory Staff, 1954; Dreimanis, 1962and Nelson, 1982).

Electromagnetic induction is a geophysical technique that involves measuring the electromagnetic conductivity (EM) of the subsurface. In the context of soil science, EM is used to assess and map soil properties. By employing EM, researchers and soil scientists can gather valuable information about the spatial distribution of soil properties, helping in the development of more accurate soil maps and management strategies.

Electromagnetic conductivity instruments, such as electromagnetic induction sensors or conductivity meters, measure the apparent electrical conductivity of the soil. This measurement is influenced by various soil properties, including moisture, texture, salinity, and carbonate content (Corwin and Rhoades, 1984 ;WiliamsandHoey, 1987; Johnston et al.,1997.,Brus et al., 1992and Iddir et al, 2019).

EM has also been associated with other ancillary soil properties such as bulk density, soil structure, ionic composition, CEC, pH, and soil organic carbon, nutrient, and CaCO3 contents(McBride et al., 1990; Hedley et al., 2004 ; Jung et al., 2005 ; Sudduth et al., 2005WiliamsandHoey, 1987and Brus et al., 1992)

The basic principle is that different soil properties have different effects on the electrical conductivity of the soil. Soil carbonate, for instance, can influence the electrical conductivity due to its ability to conduct electrical charges (Vitharana et al., 2008b).

Indeed, only few information is available about the linkages between EM measurements and CaCO3% content. We can cite the work of Vitharana et al., 2008b, Heilig et al., 2011and Doolittle and Brevik, 2014. Therefore, the CaCO3 in soil may be identified and characterized through rapid and time-saving geophysical methods, which could reduce number of soil sample. Thus, indeed the ECa could be a good estimator of CaCO3 content capable helps the monitoring of soil quality affected by agricultural practices (Vitharana et al., 2008b).

In this study, we carried out a field study on loamy clay soils cultivated and irrigated by dreep system, where we analyzed the quantitative relationship between CaCO3 and EM measured in the field. EM was obtained by means of a portable electromagnetic instrument (EM38).The EM data enabling to predict CaCO3 is tested through the comparison between CaCO3 estimated by EM and CaCO3 measured in the laboratory. We assume that the relationship between measurements of EM and CaCO3 is significant. Furthermore, we expect that measurements of ECa will enable to estimate the CaCO3 in unsampled locations.

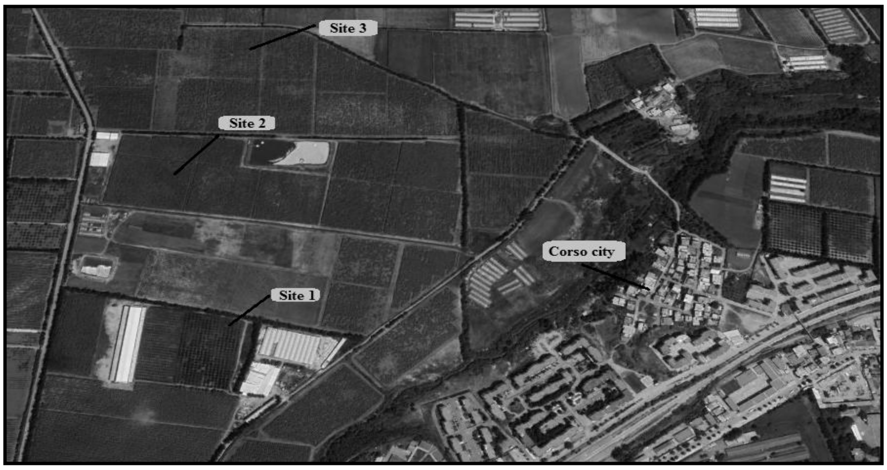
The aims of this paper is to (i) investigate the possibility of predicting CaCO3 through electromagnetic conductivity on soils cultivated and irrigated by drip system (ii) map the distribution of CaCO3 by coupling between the electromagnetic method and geostatistical methods.

2. Material and methods

Study description

The study field is located Corso district, which is located in the north of Algeria (longitudes 3°25’ to 3°29’ East and latitudes 36°46’ to 36°42’ North lat. 36°46’ to 36°42’N, long. 3°29’ E (fig 1) (The climate is subhumid(670 mm rain/year), temperate in winter with strong potential evapotranspiration (1073 mm). The soil classified as Calcic Luvisol (IUSS, 2014), with sandy clay loam to loam texture.

Three sites of the same soil type were chosen as the sampling of grounds. The first (Site 1) one is a citrus irrigated by the drip system, the second (Site 2) and the thirdsites (Site 3) are vineyard irrigated also by the drip system.



EM survey, soil sampling and laboratory analysis

The EM survey was collected by EM38 Geonics Ltd canada in the horizontal position along 3 transect located respectively at site 1, site 2 and site 3.The distance interval between each survey is 10m. At each point of EM survey, soil samples were taken by auger in at 0.30 cm to a depth of 90 cm (Fig. 2). Laboratory analysis included measurements of the particle size fractions, gravimetric water soil water content (H%) and electrical conductivity ($EC_{1:5}$), total organic matter (TOM%) and $pH_{(2:5)}$ were determined for each soil layer and weighted for the 90 cm depth (Fig. 2).

Statistical and geostatistical analysis

Classical statistical descriptors, including mean, maximum, minimum, and standard deviation, were determined. These descriptors are commonly used to summarize and describe the central tendency, variability, and distribution of data.

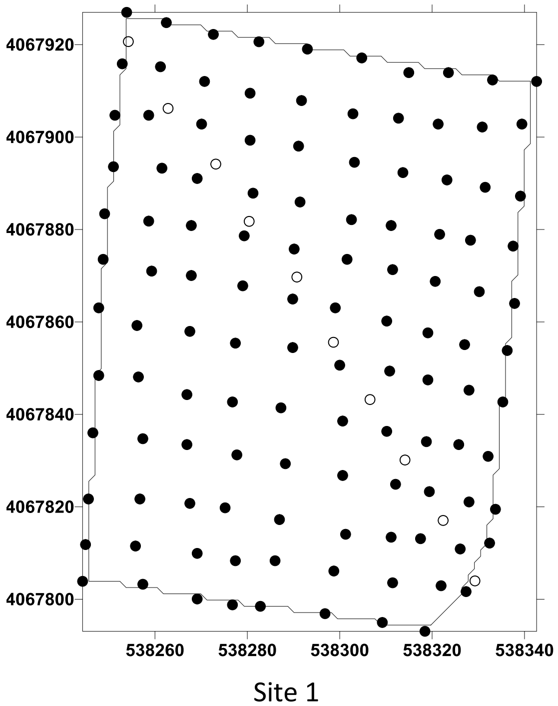
Univariate relationships between EM (Electromagnetic conductivity) and $CaCO_3$ content were studied using simple linear regression (SLR). Simple linear regression helps in understanding the linear association between two variables. The calibration equations presumably developed to relate EM and $CaCO_3$% were validated using the Wilcoxon test. The Wilcoxon test is a non-parametric statistical test used to compare paired samples.

The spatial variability dependence was analyzed by geostatistical method (variography and ordinary kriging).

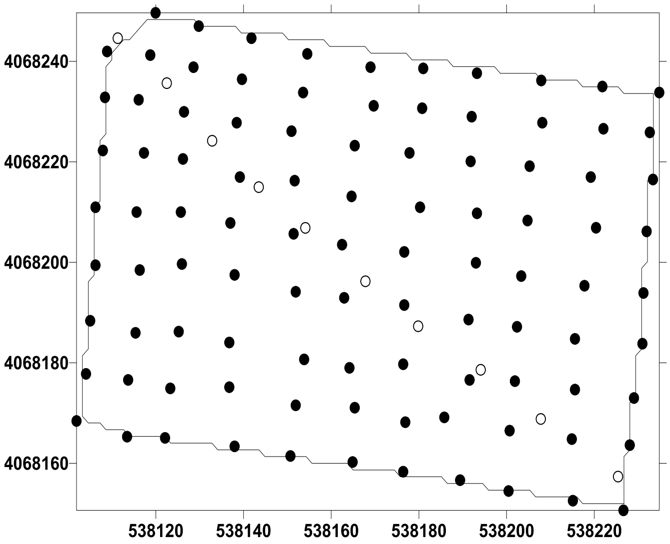
Result and discussion

Soil characteristic

Table 2 shows the mean and standard deviation of the soil physico-chemical properties:for each site. The particle size analysis indicated that the soils were clay loam. The soil were neutral (7.01 <pH< 7.3) and low in Total organic matter (2.22 % < OM < 2.9%), salinity (0.29 ms/cm < CE < 0.49 ms/cm) and water content (<15%). The result show also the CaCo3 content varies between 1.54% (Site 1) and 1.88 % (site 3). However, the results alsoshow that these properties vary spatially differently. The result reveal that the EC and $CaCO_3$ are the most variable parameters with CV > which vary between 13 and 48%. On the other hand, the texture and the pH present a homogeneous appearance with variation coefficients of less than 7%. These results indicate the presence of large differences in soil characteristics of all studied sites.



Site 1



Site 2

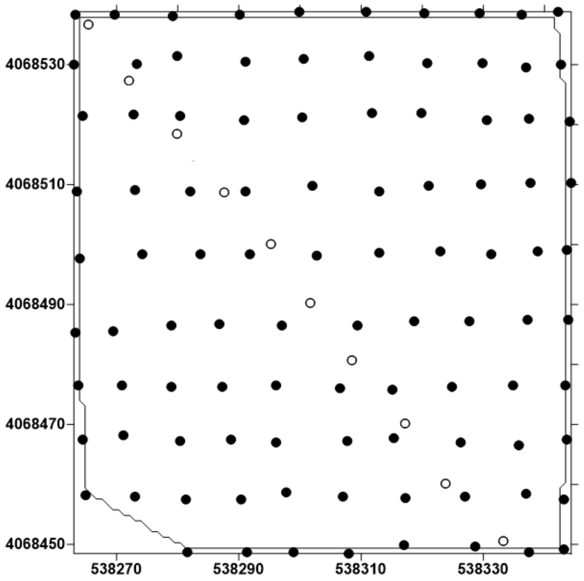


Figure 2. Soil samples (o) and EM measurment (●, o)

Table 1:Soil Characteristics of the three sites

	Site 1		Site 2		Site 3	
Clay %	30.33	5.2%	28.88	3.0%	29.79	5.0%
Silt %	28.73	6.9%	29.13	8.7%	28.53	3.9%
Sand %	40.94	7.0%	41.99	4.8%	41.68	4.2%
pH	7.43	1.1%	7.39	1.8%	7.02	2.7%
ECmS/cm	0.49	32.7%	0.29	51.7%	0.42	11.9%
$CaCO_3$ %	1.75	14.0%	1.88	37.8%	1.88	34.0%
H%	14.67	5.8%	14.8	9.1%	11.76	14.4%
TOM %	2.22	14.4%	2.9	7.9%	2.11	16.1%

Table 2: Linear regressions parameter between $CaCO_3$% and EM for the three study sites.

*** Significant at P < 0.001, respectively

	Slope	intercept	R2
Site 1	0,0196	0,71	0.91***
Site 2	0,064	-2,63	0.913***
Site 3	0,0571	-2,56	0,94***

Table 3: Descriptive statistics of CaCO3%measured and CaCO3% estimated by EM

Site 1	Min	Max	Mean	SD
CaCO3%measured	1,44	2,17	1,75	0,23
CaCO3% estimated	1,45	2,12	1,75	0,22
Site 2				
CaCO3%measured	1,33	3,52	1,88	0,71
CaCO3% estimated	1,18	3,41	1,88	0,68
Site 3				
CaCO3%measured	1,22	3,30	1,84	0,62
CaCO3% estimated	0,98	3,03	1,85	0,60

Estimation of CaCO3 by EM

The parameters of calibration equations that relate $CaCO_3$% to EM by SLR model is presented in Table 3. With R^2 ranging from 0.91 to 0.94, the determination coefficients (R2) for the three equations are statistically significant (p <0.001). This result reflects strong relationships between EM values and $CaCO_3$%. This result means that within the three sites, $CaCO_3$% can be properly predicted by the EM. Moreover, the results show that the descriptive statisticsof estimated $CaCO_3$% are similar to those of measured $CaCO_3$% (Table 4). This suggests that the EM estimate correctly the $CaCO_3$%. Indeed, calculations show that the correlations made between the $CaCO_3$% measured and that estimated by EM are statistically very highly significant (r > .95; p <0.001) (Table 5).The comparison between the measured and predicted values of $CaCO_3$% for the different study sites is illustrated in Fig. 3. This figure shows that the curves of measured $CaCO_3$% are very close to those estimated by EM, slightly lying above or below it. This result means that the $CaCO_3$% prediction using EM is reliable with a very slight over or under estimation. Non-parametric tests Wilcoxon (Table 6) confirm this result and indicate that the differences between the values of $CaCO_3$% measured and those predicted by EM were not statistically significant. Similarly, this result confirms that, in the context of this study, the $CaCO_3$% can be properly estimated by EM.

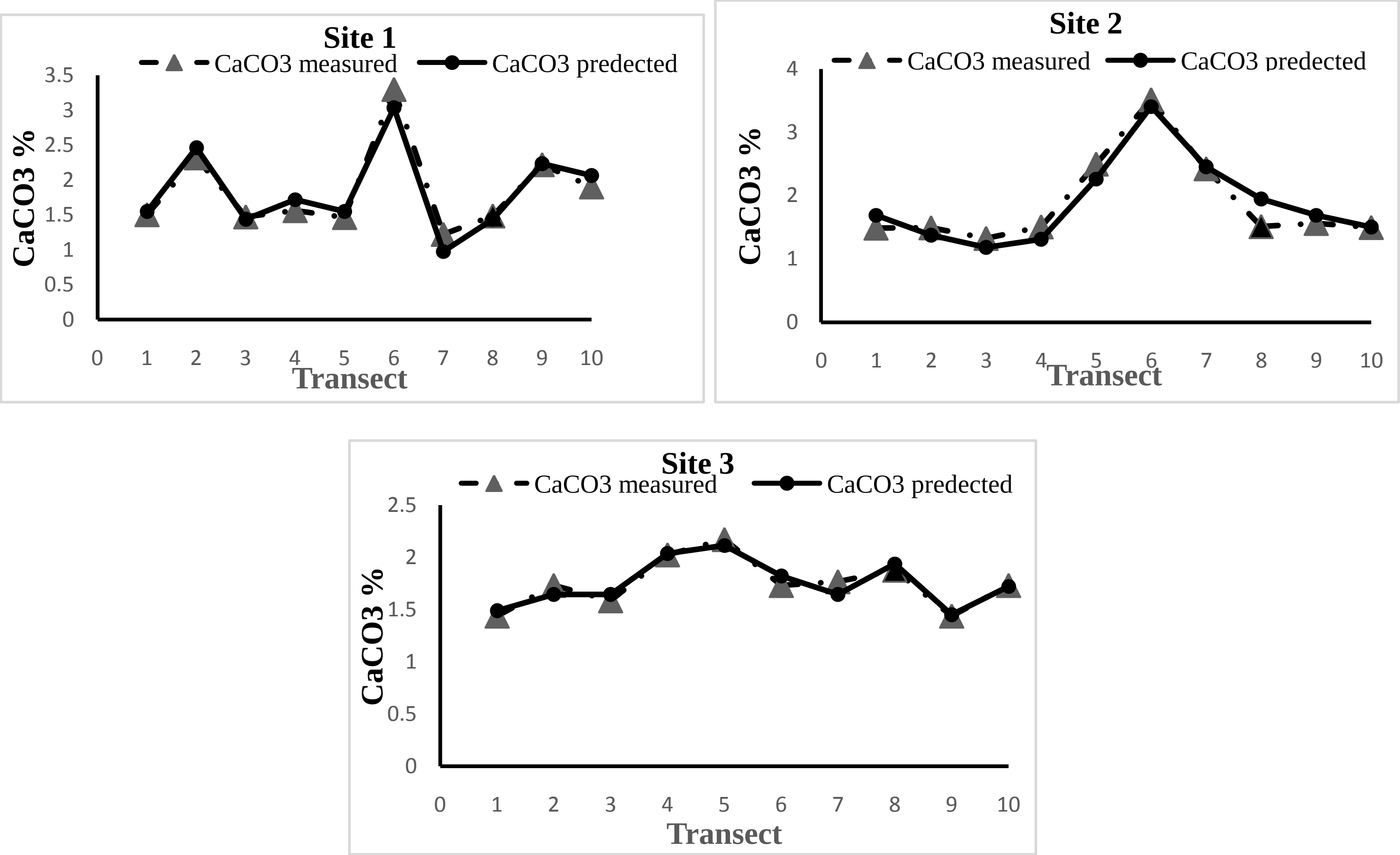


Figure 3. Comparison between measured and predected $CaCO_3$% at each site study

Table 4: Correlation between CaCO3% measured and CaCO3% predicted. *** Significant at *P* < 0.001	
Site 1	0,95***
Site 2	0,95***
Site 3	0,96***

Table 5: Sign and Wilcoxon tests between CaCO3%measured and CaCO3% estimated by EM. *Significant at P < 0.05		
	Sign test	Wilcoxon test
Site 1	0,75*	0,91*
Site2	0,75*	0,76*
Site 3	0,75*	0,83*

Calibration and Mapping

Soil electromagnetic conductivity (EM) was converted to $CaCO_3$ using the calibration equation based on a simple linear regression. Afterwards, estimated soil $CaCO_3$ data were interpolated using a geostatistical method to identify the spatial variations of this parameter using the variogram and to map the different levels of CaCO3 content using ordinary kriging.

The first step in using of kriging methods is to check the presence of spatial structure among data by variogram analysis. The best fitted semi-variogram to $CaCO_3$ data set and its parameters are displayed in figure 3. Semi-variogram models with the smallest residual sum of squares were selected as the best fitting model. The figures show that the experimental variograms are clearly structured and that they are fitted to Gaussian models. Gaussian mathematical models are often widely cited in soil science studies (Cetin andKrida, 2003; Betencourt et al.,2016and Ghorbani et al., 2018). The semivariograms present a divergence in their spatial dependence with levels sill vary between 0.025 (Site1) and 0.1 (Site 2), which explains between 68% and 77% of the total variability. Meaning that more than 68 % of the variation in CaCO3 is spatially structured with low spatial dependence nugget effect > 25 % (Cambardella et al., 1994).The semivariograms also show that the range values are more or less homogeneous and vary between 12 and 15 m. This range corresponds to the average value of the EM measurement step, which reflects good interpolation quality.

Table 6. Parameters of variogram models

	Site1	Site2	Site3
Model	Gaussian	Gaussian	Gaussian
Nugget effect (C_0)	0.0116	0.025	0.03
Sill ($C+C_0$)	0.0366	0.375	0.13
C0 / $C+C_0$ %	37.1%	60.7%	23.1%
Range effect (m)	12	15	12

Figure 4 shows interpolated maps by ordinary kriging for CaCO3% predicted by EM.
MSE and RMSE was used for comparison of the results. According to Table 4
The observation of the maps of site 2 and 3 (cultivated by vine) confirms the results obtained previously (Table 1) and confirms the great variability of the $CaCO_3$% for both sites (Fig. 4). Indeed, the maps reveals that site 3 has higher values compared to site 2. Indeed, more than 80% of the site is occupied by $CaCO_3$%superior at 2%, and if compared to the other sites, the maps of site 3 present a certain spatial homogeneity i.e. 70% of the site is occupied by $CaCO_3$% between 1 and 1.5%. This result is in consistency with those obtained by the

regression and the Wilcoxon tests and demonstrates that the $CaCO_3$% content can be well estimated and mapped through EM.

Conclusion

The aims of this paper was to investigate the possibility of predicting $CaCO_3$% through apparent electrical conductivity on irrigated soils by reclaimed wastewater and thus analyze the effect of reclaimed wastewater on $CaCO_3$%. The hole of the results shows that the $CaCO_3$% can be well estimated and mapped through ECa. The results showed that irrigation by uncluttered wastewater promotes the abundance of $CaCO_3$%. Indeed, the sites irrigated by uncluttered wastewaterhave higher $CaCO_3$% compared to the sites irrigated by conventional water. The results also show that a strong correlation between ECa and soil $CaCO_3$% was found confirming the EMI technique as a useful tool to evaluate spatial variability of soil biological parameters. This study allowed us to spatialize punctual ECa data at field scale. ECaspatialization gave a more detailed $CaCO_3$% distribution within the vineyard and citrus. EMI technique could be a useful tool to compute accurately the global $CaCO_3$%. Which is a difficult parameter to measure, because its species are very mobile in the soil. EMI technique appears to be a very efficient tool to spatialize $CaCO_3$% and biomass at field level and to locate representative soil sampling areas. Therefore, ECa method combined with the geostatistical technique seems to be reliable to estimate the mean value of $CaCO_3$% and they could become an effective strategy to reduce the number of soil samplings and, as a consequence, the cost of the evaluation procedure. This study confirms the results obtained previously and shows the effectiveness of geophysical methods for the prediction of the chimical parameters of the soil.However, more detailed studies on the evaluation of soil chimical parameters through ECa are needed especially in very different pedoclimatic scenarios.

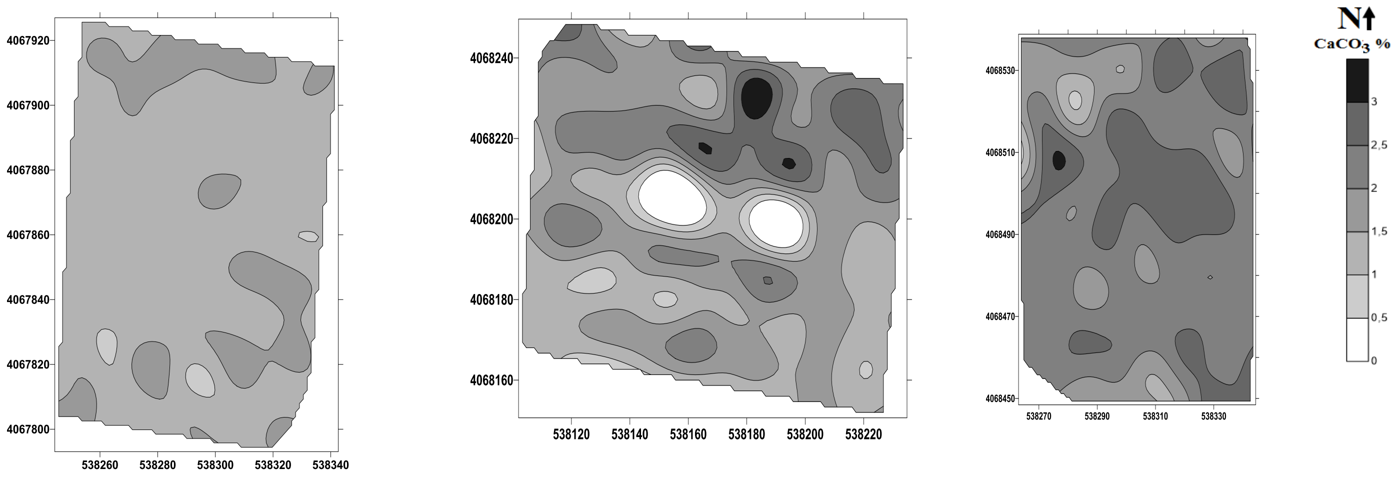


Figure. 4. Kriged contour maps of the $CaCO_3$ estimated by ECa at each study site

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