biology and life sciences forum

MDPI

Proceeding Paper

Remote Sensing (NDVI) and Apparent Soil Electrical Conductivity (EC_{ap}) to Delineate Different Zones in a Vineyard †

Catarina Esteves [1,*], Henrique Ribeiro [1,2], Ricardo P. Braga [2] and David Fangueiro [1,2]

1 Linking Landscape, Environment, Agriculture and Food (LEAF), Instituto Superior de Agronomia, Universidade de Lisboa, Tapada da Ajuda, 1349-017 Lisboa, Portugal; henriqueribe@isa.ulisboa.pt (H.R.); dfangueiro@isa.ulisboa.pt (D.F.)
2 Departamento de Ciências e Engenharia de Biossistemas (DCEB), Instituto Superior de Agronomia, Universidade de Lisboa, Tapada da Ajuda, 1349-017 Lisboa, Portugal; ricardobraga@isa.ulisboa.pt
* Correspondence: catarinaesteves@isa.ulisboa.pt
† Presented at the 1st International Electronic Conference on Agronomy, 3–17 May 2021; Available online: https://sciforum.net/conference/IECAG2021.

Abstract: The intensification of agriculture has greatly enhanced crop productivity, but also its potential environmental impact. Nutrient recycling and an increase in resource use efficiency are the key points to keep production at high levels with minimum impact. The present work's goal was to provide new insight on the spatial variability of soil chemical properties in a vineyard. For this, three different zones were identified in a 6.77 ha parcel, according to the remote sensing of apparent soil electrical conductivity (EC_{ap}) and the normalized difference vegetation index (NDVI). Soil samples from specific locations were then collected and chemically described, and the resulting data were statistically analyzed. EC_{ap} and NDVI appeared to be efficient tools to define different zones within the vineyard, with most of the soil chemical properties varying at the highest significance level ($p < 0.001$) according to the F test, except for extractable phosphorus (Égner-Rhiem) and organic carbon (TOC method). Overall, our results revealed potential for the implementation of site-specific soil fertilization and soil quality management.

Keywords: apparent soil electrical conductivity; normalized difference vegetation index; soil sampling; precision fertilization; vineyard

Citation: Esteves, C.; Ribeiro, H.; Braga, R.P.; Fangueiro, D. Remote Sensing (NDVI) and Apparent Soil Electrical Conductivity (EC_{ap}) to Delineate Different Zones in a Vineyard. *Biol. Life Sci. Forum* **2021**, *3*, 42. https://doi.org/10.3390/IECAG2021-10021

Academic Editor: Youssef Rouphael

Published: 11 May 2021

1. Introduction

The intensification of agricultural systems with the sole purpose of increasing a crop's productivity is no longer viable nor sustainable. The technologies that are being developed and have emerged in the last two or three decades have allowed for the modernization of food production systems and can maintain highly productive crops while reducing the consequent environmental impacts. This is the case for Precision Agriculture (PA), a food production system based on the variable and precise use of inputs to match a specific site's characteristics and determine the adequate timing of application, i.e., it can adjust the amount of input material used to achieve optimal yield [1,2].

As a result, resource use efficiency is improved by generating fewer losses to the environment with more economic benefits, in contrast to conventional, uniform management [2–4]. Consequently, there is an opportunity for PA practices to tackle climate change, since the amount of production inputs responsible for greenhouse gas emissions (e.g., fertilizers, pesticides, and irrigation) is reduced [2]. When PA technologies are applied for fertilization purposes, crop productivity and quality are expected to be higher, and yields are more stable [5].

However, the delineation of homogenous fertility zones within a field, which allows for the site-specific management of production inputs, remains difficult to implement due to the complex relationships between soil nutrients and the vast spatial variability of soil's chemical and physical properties, which are responsible for variations in crop production [6]. Therefore, the intra-field variability must be known or quantified, which can be achieved through the mapping of relevant variables or attributes [7], such as the soil's physical and chemical properties.

To identify such attributes, the current paper presents two examples. The first is field-scale apparent soil electrical conductivity (EC_{ap}) maps that are used to measure various soil characteristics, such as salinity, water content, clay content, organic matter, and many other characteristics that are known to mutually influence soil's electrical conductivity [6,8]. Altogether, interpretation of EC_{ap} maps is a very complex process, requiring expertise and ground-truth soil samples; however, it is known to be a fundamental economic tool to strategically choose sampling locations, reducing the number of samples needed to describe the spatial variability of soil's physical and chemical properties [8], which otherwise would be very time and cost consuming.

Second, NDVI, which is also very common and well-recognized in PA, is correlated with several crop parameters, such as plant physiology, crop yield, and production biomass [9]. The expression used to obtain the mentioned vegetation index is extensively described in the literature (e.g., [10,11]), where the bands from the near infrared radiation (NIR) region (from 0.7 to 1.2 μm) and the red radiation region (from 0.6 to 0.7 μm) are used for the computation. The indicator varies from +1 to −1, where positive values represent vegetation or high-reflective surfaces, since they have a higher reflectance of NIR radiation, and negative values indicate non-vegetation or senescent and dry vegetation, or clouds and water, as they have a lower reflectance of NIR radiation [11].

In the present work, these two indicators were used in combination to select different zones within a vineyard. Three different zones were selected, and soil samples were collected in specific locations and later analyzed. Afterwards, a statistical analysis was done to determine if (1) these tools were effective in the delineation of different zones within a field and (2) if there is a potential for the implementation of precision fertilization within the vineyard.

2. Materials and Methods

2.1. Experimental Site

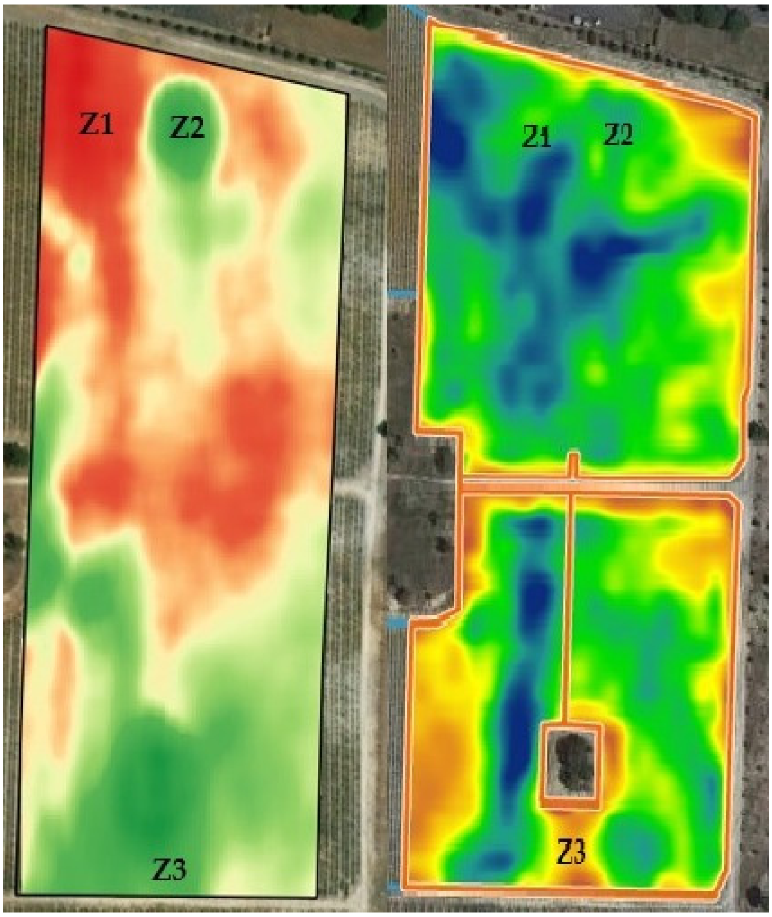
The experimental site is located in a vineyard of *Vitis vinifera* L. in Montijo, Portugal (38°41′25.9″ N 8°45′40.8″ W). The selected study area is 6.77 ha, and the vines are spaced 1.4 m by 2.8 m.

The soil was primarily classified as an Orthic Podzol, according to the World Reference Base for soil classification [12]. The region's climate is a Csa, a temperate climate with a rainy winter and a dry summer, according to the Köppen-Geiger climate classification [13].

The vineyard has a drip irrigation system that provides water during the months of June and July, over berry formation. The vineyard soil is fertilized once a year, after the dormant season, with an organic fertilizer (4.2:4.5:1 in N:P:K units and has a 65% organic matter content) at a rate of 1000 kg ha^{-1}. The organic fertilizer is applied in the form of 4 mm pellets at a 40 cm depth in alternate inter-rows.

2.2. Experimental Design

In the present study's field, it was only possible to establish 3 levels of combinations with NDVI and EC_a, as seen in Figure 1, based on their high and low values. And so, three zones were selected as follows: zone one (Z1) has high levels of NDVI and low of EC_a, zone two (Z2) has high levels of both NDVI and EC_a, and zone three (Z3) has low NDVI and high EC_a. High and low levels were defined based on the 50 percentile values.



(**a**) (**b**)

Figure 1. The figure shows the location of the three delineated zones based on the (**a**) remote measurement of EC_{ap}, where green and red represent high and low values of EC_{ap}, respectively, and (**b**) the remote sensing of NDVI, where blue represents high and positive values and red represents low and negative values.

2.3. NDVI and EC_{ap}

The EC_a map was kriged from an electromagnetic induction (EMI) sensor and an EM38-MK2 sensor (Geonics EM38®) [14], and the data were obtained on 14 May 2018. The sensor was mounted on a four-wheel motorcycle that passed between every other inter-row (intervals of 5.6 m). The soil had a water content of about 75% of field capacity. To verify if the metal wires interfered with EC_{ap} measurement, after obtaining the EC_{ap} maps, we performed a field validation. There was a good fit between the values in the maps and the actual soil texture.

The NDVI maps was obtained from the European Commission's Copernicus program, from the satellite Sentinel-2 [15] on 24 June 2018.

2.4. Soil Analysis

Soil samples were collected in the summer of 2019, from the first 0-50 cm of arable soil. Prior to being chemically analyzed, soil samples were air-dried until they reached a constant weight and sieved through a 2-mm mesh. The chemical properties assessed in the present study were the following: pH and laboratory-determined soil electrical conductivity ($EC_{1:2.5}$), soil organic carbon (SOC), total nitrogen (N), extractable P and potassium (K), exchangeable cations K^+, Ca^{2+}, Mg^{2+}, and Na^+, exchangeable acidity (EA), sum of bases (SB), base saturation percentage (BSP), and cation exchange capacity (CEC). The last-mentioned properties were calculated using the following expressions (1):

$$SB = K^+ + Ca^{2+} + Mg^{2+} + Na^+,\ CEC = SB + EA,\ BSP = SB/CEC, \quad (1)$$

Both pH and $EC_{1:2.5}$ were measured in a 1:2.5 soil:water suspension prepared with distilled water, using a potentiometer and an electrical conductivity meter at room temperature. pH was measured in a 1:2.5 soil:$CaCl_2$ (0.01 M) suspension.

Extractable P and K were determined using the Égner-Rhiem method and measured through the Inductively Coupled Plasma (ICP-OES) technique; SOC concentration was determined through the total organic carbon (TOC) method using dry combustion; and total N was measured using the Kjeldahl method. Exchangeable cations were determined by extraction with ammonium acetate and then quantification through the ICP-OES technique, and EA was determined through KCl (1 M) extraction, followed by titration with NaOH (0.043475 M).

Particle size determination was also evaluated in the present work and was measured through the conventional Pipette Method to obtain the soil's percentages of sand, silt, and clay.

2.5. Statistical Analysis

To determine if the established management zones were significantly different, the experimental data were analyzed through an analysis of variance, using the General Linear Model (GLM) procedure for factorial design and F-tests. Means separation was then performed using the LSD test with the significance level set at $\alpha = 0.05$. All statistical analysis was completed through the Statistix software package [16].

3. Results and Discussion

Statistical analysis revealed that most of the selected soil properties significantly varied between zones, at a high significance level ($p < 0.001$) according to the F test (Tables 1 and 2). In contrast, SOC and extractable P did not significantly vary with zones. In fact, the SOC values observed are relatively low, as expected in an aged vineyard [17], and are very homogeneous. Therefore, in the event of organic matter supplementation, it should be homogeneous in the entire field area, which it currently is, considering that the studied vineyard uses a conventional uniform fertilization application across its field.

Table 1. The effect of zone on soil pH (extracted with H_2O and with $CaCl_2$), soil electrical conductivity extracted in a 1:2.5 soil:water proportion ($EC_{1:2.5}$), soil organic carbon (SOC), total N, and extractable P and K.

Zones	pH	pH	$EC_{1:2.5}$	SOC	N_{tot}	Extractable P	Extractable K
	(H_2O)	($CaCl_2$)	($\mu S\ cm^{-1}$)	(%)	(mg kg^{-1})		
Signif.	**	***	***	*ns*	***	*ns*	***
Z1	6.25 b	5.36 b	64.60 b	0.42	255.30 b	19.85	56.90 b
Z2	6.48 a	5.35 b	81.11 b	0.42	315.98 a	18.55	91.50 a
Z3	6.51 a	5.70 a	161.27 a	0.42	179.85 c	8.83	90.33 a

Signif.—significance level by the F test, *ns*—non-significant at $p < 0.05$ level, significant at $p < 0.01$ (**) and at $p < 0.001$ (***) by the F test. In each column, values followed by the same letter do not significantly differ by the LSD test at $\alpha = 0.05$.

Table 2. The effect of zone on the selected soil exchangeable cations, exchange acidity (EA), cation exchange capacity (CEC), sum of bases (SB), and base saturation percentage (BSP).

Zones	Exchangeable Cations				EA	CEC	SB	BSP
	K^+	Ca^{2+}	Mg^{2+}	Na^+				
	($cmol^+ kg^{-1}$)							%
Signif.	***	***	***	***	***	***	***	***
Z1	0.15 b	1.66 b	0.45 c	0.04 b	0.11 c	2.40 c	2.30 c	94.46 a
Z2	0.23 a	2.01 b	1.07 b	0.09 b	0.33 a	3.74 b	3.41 b	90.04 b
Z3	0.23 a	3.03 a	2.96 a	0.43 a	0.22 b	6.87 a	6.65 a	96.35 a

Signif.—significance level by the F test, *ns*—non-significant at $p < 0.05$ level, significant at $p < 0.001$ (***) by the F test. In each column, values followed by the same letter do not significantly differ by the LSD test at $\alpha = 0.05$.

The differences observed in this data suggest that the zones are distinct from each other, thus indicating a potential for differential management of soil fertility and simultaneously demonstrating the efficiency of EC_{ap} and NDVI in selecting different zones within the vineyard. This is not a novel result, as EC_{ap} and NDVI have already been successfully used to delineate management zones in vineyards [18], nevertheless, is still a strong indicator of the usefulness of using remote data to study soil spatial variability. In another case, where EC_{ap} was used exclusively, the indicator was highly correlated with pH, with soil organic matter content, and with electrical conductivity, but was not correlated with soil P content [19]. This outcome is similar to that of the present study in regard to pH and EC and also with the lack of P variations within the selected zones. Even when adding NDVI as a discriminatory variable, no variations are obtained for soil P, confirming the difficulty of identifying homogenous zones within a field for Precision Fertilization.

Additionally, there is a tendency for higher soil N_{tot} content in zones with high NDVI values, as Z2 and Z1 (zones with high NDVI), in this order, presented the highest N_{tot} content. The correlation of NDVI with soil N content has been extensively studied (e.g., [20]), and so the outcome was expected. Nevertheless, NDVI was a vital component in the delineation of zones within the vineyard and showed the potential for differential N fertilization in the present vineyard.

In respect to $EC_{1:2.5}$, Z3 presented the highest value, twice as high as Z2. Regarding pH (H_2O), zones with high EC_{ap} (Z3 and Z2) had the highest result. In the case of pH ($CaCl_2$), it was highest in Z3. Calcium Chloride pH determination can be more reliable in the determination of salts concentration in the soil solution when compared to H_2O determination [21], which is verified here, since Z3 is the zone with highest content of salts, K^+, Ca^{2+}, Mg^{2+}, and Na^+, as seen in Table 2, explaining the difference between pH (H2O) and pH (CaCl2) results. Again, Z3 presented the highest value of CEC, SB, and BSP; the latter was also high in Z1, due to the calculation of low SB divided by low CEC. Therefore, the present vineyard verifies the relationship between EC_{ap} and soil properties dependent or related to salt concentration in the soil solution, demonstrating the convenience and practicality of using this indicator for soil fertility management.

Regarding the soil's percentages of sand, silt, and clay, as shown in Table 3, the results revealed that Z2 and Z3 presented higher contents of clay and lower of sand, significantly contrasting with Z1.

Table 3. The effect of zone on the percentage of sand, silt, and clay in the soil samples.

Zones	Sand	Silt	Clay
		%	
Signif	***	***	**
Z1	85.06 a	5.71 b	9.23 b
Z2	73.43 b	8.58 a	18.00 a
Z3	71.16 b	6.67 b	22.17 a

Signif.—significance level by the F test, *ns*—non-significant at $p < 0.05$ level, significant at $p < 0.01$ (**) and at $p < 0.001$ (***) by the F test. In each column, values followed by the same letter do not significantly differ by the LSD test at $\alpha = 0.05$.

This outcome is in accordance with the above results, since soils with high clay contents are expected to have higher CEC [22], as the exchange surfaces in clay minerals adsorb exchangeable cations and consequently increase exchangeable cations that can be exchanged and absorbed by the plants. This relationship has already been studied using remote data, showing the strong correlation between EC_{ap} and clay content and CEC, concerning all types of EC_{ap} data and across a multitude of fields [23]. Another researcher found that EC_{ap} explained extractable Na^{+} and Mg^{2+} as well as sand and clay content, particularly in a vineyard in California [24].

4. Conclusions

The results showed high efficiency in combining the indicators EC_{ap} and NDVI for the delineation of three distinct zones within the vineyard in respect to the assessed soil properties, except for SOC and extractable P. As such, the studied area does show potential for site-specific management of soil fertilization and soil health. However, a subsequent step to properly quantify the potential of PF implementation should be to perform yield and cost analyses.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/IECAG2021-10021/s1.

Author Contributions: Conceptualization, D.F., H.R. and R.P.B.; writing—original draft preparation, C.E.; writing—review and editing, C.E., D.F. and H.R.; methodology, H.R. and R.P.B.; visualization, C.E.; formal analysis, C.E., H.R. and R.P.B.; investigation, C.E.; resources, D.F., H.R. and R.P.B.; data curation, C.E., H.R. and R.P.B.; funding acquisition, D.F. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by (1) the Project Nutri2Cycle: H2020-SFS-30-2017- "Transition towards a more carbon and nutrient efficient agriculture in Europe", funded by the European Union, Program Horizon 2020 (Grant Agreement No 773682); (2) LEAF (Linking Landscape, Environment, Agriculture and Food Research Unit), funded by FCT (UID/AGR/04129/2020). This document reflects only the authors' views, and the Union is not liable for any use that may be made of the information contained therein.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

1. Du, Q.; Chang, N.B.; Yang, C.; Srilakshmi, K.R. Combination of multispectral remote sensing, variable rate technology and environmental modeling for citrus pest management. *J. Environ. Manag.* **2008**, *86*, 14–26. [CrossRef] [PubMed]
2. Balafoutis, A.; Beck, B.; Fountas, S.; Vangeyte, J.; Van Der Wal, T.; Soto, I.; Gómez-Barbero, M.; Barnes, A.P.; Eory, V. Precision agriculture technologies positively contributing to ghg emissions mitigation, farm productivity and economics. *Sustainability* **2017**, *9*, 1339. [CrossRef]
3. Van Alphen, B.J.; Stoorvogel, J.J. A methodology for precision nitrogen fertilization in high-input farming systems. *Precis. Agric.* **2000**, *2*, 319–332. [CrossRef]
4. Nawar, S.; Corstanje, R.; Halcro, G.; Mulla, D.; Mouazen, A.M. *Delineation of Soil Management Zones for Variable-Rate Fertilization: A Review. Advances in Agronomy*, 1st ed.; Elsevier Inc.: Amsterdam, The Netherlands, 2017; Volume 143. [CrossRef]

5. Haneklaus, S.; Schnug, E. Impacts of precision agriculture technologies on fertilization. In Proceedings of the 11th international symposium of CIEC "Codes of Goof Fertilizer Practice and Balanced Fertilization", Pulawy, Poland, 27–29 September 1998; pp. 95–107.
6. Peralta, N.R.; Costa, J.L. Delineation of management zones with soil apparent electrical conductivity to improve nutrient management. *Comput. Electron. Agric.* **2013**, *99*, 218–226. [CrossRef]
7. Leroux, C.; Tisseyre, B. How to measure and report within-field variability: A review of common indicators and their sensitivity. *Precis. Agric.* **2019**, *20*, 562–590. [CrossRef]
8. Corwin, D.L.; Lesch, S.M. Apparent soil electrical conductivity measurements in agriculture. *Comput. Electron. Agric.* **2005**, *46*, 11–43. [CrossRef]
9. Verhulst, N.; Govaerts, B.; Sayre, K.D. Using NDVI and soil quality analysis to assess influence of agronomic management on within-plot spatial variability and factors limiting production. *Plant Soil* **2009**, *317*, 41–59. [CrossRef]
10. Aldakheel, Y.Y. Assessing NDVI Spatial Pattern as Related to Irrigation and Soil Salinity Management in Al-Hassa Oasis, Saudi Arabia. *J. Indian Soc. Remote Sens.* **2011**, *39*, 171–180. [CrossRef]
11. Bhunia, G.S.; Shit, P.K.; Pourghasemi, H.R. Soil organic carbon mapping using remote sensing techniques and Soil organic carbon mapping using remote sensing techniques and multivariate regression model. *Geocarto Int.* **2017**, *34*, 215–226. [CrossRef]
12. WRB-IUSS. *World Reference Base for Soil Resources*; World Soil Resources Reports 106. World Soil Resources Reports No. 106; Food & Agriculture Organization: Rome, Italy, 2015.
13. Instituto Português da Atmosfera e Do Mar. Available online: https://www.ipma.pt/pt/oclima/normais.clima/ (accessed on 27 March 2021).
14. Geonics Limited. Available online: http://www.geonics.com/html/em38.html (accessed on 27 March 2021).
15. Copernicus Sentinel-2, Overview of Mission at. Available online: https://sentinel.esa.int/web/sentinel/missions/sentinel-2 (accessed on 15 April 2021).
16. *Statistix Program Version 9.0*; Free Trial; Analytical Software: Tallahassee, FL, USA. Available online: https://www.statistix.com/ (accessed on 27 March 2021).
17. Lanyon, D. The Effect of Soil Properties on Zn Adsorption. *J. Int. Environ. Appl. Sci.* **2016**, *12*, 151–160. Available online: https://www.researchgate.net/publication/228433458 (accessed on 10 July 2021).
18. Tagarakis, A.; Liakos, V.; Fountas, S.; Koundouras, S.; Gemtos, T.A. Management zones delineation using fuzzy clustering techniques in grapevines. *Precis. Agric.* **2013**, *14*, 18–39. [CrossRef]
19. Peralta, N.R.; Cicore, P.L.; Marino, M.A.; da Silva, J.R.M.; Costa, J.L. Use of geophysical survey as a predictor of the edaphic properties variability in soils used for livestock production. *Span. J. Agric. Res.* **2015**, *13*, 29. [CrossRef]
20. Peri, P.L.; Rosas, Y.M.; Ladd, B.; Toledo, S.; Lasagno, R.G.; Pastur, G.M. Modeling soil nitrogen content in south Patagonia across a climate gradient, vegetation type, and grazing. *Sustainability* **2019**, *11*, 2707. [CrossRef]
21. Kissel, D.E.; Sonon, L.; Vendrell, P.F.; Isaac, R.A. Salt concentration and measurement of soil pH. *Commun. Soil Sci. Plant Anal.* **2009**, *40*, 179–187. [CrossRef]
22. Corwin, D.L.; Scudiero, E. Field-Scale Apparent Soil Electrical Conductivity. *Methods Soil Anal.* **2016**, *84*, 1405–1441. [CrossRef]
23. Sudduth, K.A.; Kitchen, N.R.; Wiebold, W.J.; Batchelor, W.D.; Bollero, G.A.; Bullock, D.G.; Clay, D.E.; Palm, H.L.; Pierce, F.J.; Schuler, R.T.; et al. Relating apparent electrical conductivity to soil properties across the north-central USA. *Comput. Electron. Agric.* **2005**, *46*, 263–283. [CrossRef]
24. Rodríguez-Pérez, J.R.; Plant, R.E.; Lambert, J.J.; Smart, D.R. Using apparent soil electrical conductivity (ECa) to characterize vineyard soils of high clay content. *Precis. Agric.* **2011**, *12*, 775–794. [CrossRef]