Soil spatial variability at vineyard scale and relationship between grape elemental profile and enological characteristics of Aglianico grapewine in Taurasi DOCG area

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This PhD thesis concerned the characterization of the SOIL-GRAPE-WINE system and the possible relationships between soil properties and enological characteristics/quality of grapes and wines. A multidisciplinary approach, including spatial, pedological and enological analyses, was applied to identify possible key factors of the soil-vineyard interaction to be used in the precision viticulture framework.

Variabilità spaziale del suolo a scala di vigneto e relazione tra profilo elementare dell'uva e caratteristiche enologiche del vitigno Aglianico nell’areale del Taurasi DOCG

Questa tesi di dottorato ha riguardato la caratterizzazione del sistema SUOLO-UVA-VINO e le possibili relazioni tra proprietà del suolo e caratteristiche enologiche/qualità delle uve e dei vini. È stato applicato un approccio multidisciplinare, comprendente analisi spaziali, pedologiche ed enologiche, per identificare possibili fattori chiave dell'interazione suolo-vigneto da utilizzare nel quadro della viticoltura di precisione.

**Key words**: Terroir; soil proximal sensors; grape elemental profile; grapes and wine enological characteristics.

# **1. Introduction**

Identification of viticultural *Terroir* peculiarities enhances our understanding on why specific geographical areas contribute to the quality and uniqueness of wines. Indeed, the complex soil-plant interaction affects plant metabolism at different extent and, consequently, influences the enological characteristics of grapes and wines (White RE, 2020). The concept of *terroir* has been increasingly used to attribute a specific geographical connotation to products of excellence, such as wine. As stated by the OIV (International Organization of Vine and Wine) a viti-vinicultural *Terroir* is the result of the environmental influence of climate, geology and soil on vine behavior, in interaction with the variety, agrotechniques and wine making techniques (OIV/VITI Res. 333/2010). Since that, investigations on different environmental factors (i.e., climate, geomorphology, soil, rock) and their effect on grapes and wine quality have been performed by different authors (Van Leeuwen et al., 2018). However, less investigated has been the elemental profile of grapes in relationship with their enological properties, and the variability of both composition and enological characteristics because of the soil spatial variability at vineyard scale.

# **2. Environmental setting**

This study focused on 3 vineyards (Vineyard A, B and C) from Irpinia land, all located in the clayey and marls hilly landscape of the Montemarano (AV) town, the core of Taurasi DOCG area, and applied on Aglianico red grape-variety. The aim was the identification of HZs at vineyard scale, in which sample and analyse grapes at two vintage times (2021 and 2022 years) for the identification of both their elemental profile (i.e., macro and micro element composition) and enological characteristics.

# **3. Materials and Methods**

**3.1 Vineyard selection**

The 3 vineyards located at 483, 589, and 630 m a.s.l. respectively, presented the same VCR7 clone of grape variety Aglianico cv, with the same rootstock (1103P and 420A) used. The planting year, spurred cordon training system, and NE rows orientation are also consistent across the vineyards.

**3.1 Proximal Soil Sensors (PSS)**

Soil spatial variability assessment was performed by using PSS to identify and map HZs. In detail, Gamma Ray spectrometer was used to determine Th (ppm), U (ppm) and K (%) content, while electromagnetic induction (EMI) sensor was applied to determine apparent electrical conductivity (ECa) at different depths (50, 100 and 180 cm). Then, a portable X-ray fluorescence sensor was used to determine soil major and trace total element content. All parameters were spatialised by ordinary kriging and mapped with QGIS software.

**3.2 Pedological profiles: soil chemical and physical analysis**

Pedological profiles and hand drillings were performed in the HZs, and sampling performed following soil horizons were sampled. Soil samples were analysed for their principal chemical and physical properties (including pH, Electrical Conductivity – EC, carbon content, total carbonates, cation exchange capacity - CEC, soil texture and bioavailable P2O5) following SISS methods (Analisi chimica del suolo (2021) FrancoAngeli Ed). In each HZs, grape sampling was addressed for both vintages 2021 and 2022.

**3.3 Grape analysis**

At harvest time, grape samples were collected to analyse enological parameters related to technological maturation. Parameters such as °Brix, pH, Titratable Acidity (TA), 50 berries weight and volume on 200 mL were determined immediately after harvest, on fresh samples. To assess the phenolic profile, phenolic compounds were extracted from skins and seeds using a simulated maceration process in a wine-like solution. The extracted liquid, enriched with phenolic compounds, underwent analysis using various techniques. High-Performance Liquid Chromatography (HPLC) was employed to quantify native anthocyanins, while Harbertson's assay was used to measure Total Anthocyanins, Bound Anthocyanins (LPP+SPP), BSA reactive Tannins, and Iron Reactive Polyphenols (IRPs). Spectrophotometric analyses determined the Color Index CI (sum of abs 420, 520, and 620 nm) and HUE (420/520 nm ratio). These analyses provided valuable insights into the phenolic composition of the grapes.

**3.4 Nano-vinification experiments: wine analysis**

Nano-vinification experiments were carried on the Vineyards A and B for the vintages 2021 and 2022. Grapes were sampled in two selected HZs for each vineyard, based on the maps obtained by the PSS. To standardize the fermentation conditions and minimize variations caused by natural yeasts present on the grape skins, the nano-vinification experiments involved the inoculation of the crushed grapes with a commercial yeast strain. Standardizing the fermentation conditions helps ensure reproducibility and allows for a more accurate evaluation of the impact of soil variations of the phenolic profile and other characteristics of the wines produced from grapes harvested in the different soil zones.

**3.5 Grape elemental composition analyses**

Grape skin, pulp and seeds were carefully separated, freeze-dried (skin and seeds) and homogenated after their digestion for 40 min in a microwave digester at 200°C with HNO3. Grape elemental composition was then determined using ICP-OES Thermo-Fisher.

**5. Results and Discussion**

**5.1 Mapping of Homogeneous Zones (HZs)**

The use of PSS enabled to identify and mapping HZs within each vineyard. PSS data were interpolated by ordinary kriging and maps produced by QGis software. The maps reported in Figure 1 serve as a visual representation of the HZs within each vineyard, enabling a better understanding of the spatial variability of soil properties, which could potentially impact grape growth and development, as well as grape and wine quality and enological characteristics. Indeed, a more targeted sampling approach was implemented for the grapes in the vintages of 2021and 2022.

Based on the EMI maps, the following HZs were identified:

* Vineyard A: five different HZs
* Vineyard B: five different HZs
* Vineyard C: four different HZs

Maps of gamma-ray emissions are generally consistent with EMI, then the identified HZs were used to address the pedological survey.



Figure 1 EC 180 cm mapswhich were utilized to identify and define the different HZs within the vineyards.

**5.2 Soil chemical and physical properties**

Results of soil chemical and physical analyses showed that Vineyard A, Vineyard B and Vineyard C were characterized by different soil properties.

Here is a breakdown of the findings:

Vineyard A:

The pH was moderately alkaline in Profile 1 (P1) (8.35 average value AV), Profile 2 (P2) (8.28 AV) and Profile 5 (P5) (8.16 AV), indicating a slight increase of alkalinity with depth. In Profile 3 (P3) and Profile 4 (P4) the pH showed values ranging between neutral and slightly alkaline (7.51 AV in P3 and 7.59 AV in P4). P3 and P4 exhibited the lowest pH among the mentioned profiles. Soil EC had an AV of 247.3 mS/cm in P1 (range from 127.9 to 483 mS/cm), an AV of 96.4 mS/cm in P2, (range from 102.3 on the surface to 90.8 mS/cm going deeper) and an AV of 127.1 mS/cm in P5 (range from 104.3 to 147.8 mS/cm). EC values in mentioned profiles showed a slight decrease with depth. Similar to the pH trend, EC values were higher in P1, P2 and P5. In P3 EC had an AV of 55.2 mS/cm (range from 33.2 to 76.4 mS/cm) and in P4 had an AV of 65.5 mS/cm (range from 48.4 in the deepest horizon to 87.4 mS/cm in the most superficial horizon). As for pH values, the lowest EC values found for P3 and P4.

Regarding the C content, the AV was 4.24 g/kg and decreased with depth (ranging from 7.27 to 1.54 g/kg) in P1, 3.58 g/kg AV and range from 1.46 to 8.19 g/kg in P2, an AV of 3.07 g/kg with a range from 0.83 to 8.51 g/kg in P5. As expected, a regular decline of organic matter content was observed with depth for all the analyzed soil profiles, then no buried soils occur in the stratigraphic sequence. Moreover, P1, P2 and P5 showed the lowest values for C content. In P3, C content had an AV of 12.08 g/kg and ranged from 10.54 to 15.32 g/kg, while in P4, C content AV was 11.95 g/kg and ranged from 3.30 in the deepest horizon to 16.27 g/kg, which was the highest value among all the profiles in vineyard A. Then, the soil profiles showing the highest C content were in P3 and P4.

TC content showed an average value of 68.69 g/kg in P1, an average value of 77.11 g/kg in P2, and an average value of 72.39 g/kg in P5. Interestingly, the trend of increasing values with depth was not consistently followed in P1 (ranging from 43.9 to 88.9 g/kg, with the lowest value recorded in the 120-155 cm horizon) and in P2 (minimum 29.7 g/kg at 60-70 cm, maximum 139.1 g/kg at 20-60 cm). This deviation from the expected trend suggested local variations in the carbonate distribution within the soil profile. In P5, the average TC was 72.39 g/kg with a range from 7.7 g/kg in the more superficial horizon to 174.4 g/kg in the deeper horizon. In P5, there was a clear tendency for total carbonates to increase as the depth of the horizons deepened.

In P3 and P4, there were the lowest values for TC, in accordance with pH, EC and C values. In P3, TC had an AV of 1.38 g/kg, which was the lowest among the mentioned profiles, while P4 had an AV of 2.30 g/kg.

Vineyard B:

Vineyard B exhibited a moderately alkaline pH (8.18 AV in P5, 8.30 AV in P1, 8.35 AV in P3, 8.39 AV in P2 and 8.42 AV in P4). EC values in P1 (76.9 mS/cm AV) and in P3 (89.8 mS/cm AV) were the lowest along the mentioned profiles, while in P5 (114.5 mS/cm AV), in P2 (149.5 mS/cm AV) and in P4 (205.2 mS/cm AV) values were higher. There were slight variations in the range of EC values, with a not constant trend to increase as the depth of the horizons deepen.

C content showed the highest value in P1 (6.40 g/kg AV) and the lowest in P4 (2.55 g/kg AV), while in P2 (3.21 g/kg AV), in P3 (3.39 g/kg AV) and in P5 (3.29 g/kg AV) differences were slightly moderate. In P4, C content had the lowest value (2.55 g/kg AV) and showed a considerable range in the C content (from 0.56 to 9.50 g/kg).

TC values didn't show consistent variations among the mentioned profiles (190.60 g/kg AV in P1, 150.60 g/kg AV in P2, 193.77 g/kg AV in P3, and 144.96 g/kg AV in P4). Only P5's TC value completely detached from the other profiles, with an AV of 10.64 g/kg. The lower pH, moderate electrical conductivity, lower carbon content, and lower total carbonates in P5 suggested a different soil composition compared to the other profiles of Vineyard B. Overall, Vineyard A showed more distinct differences between profiles in terms of pH, EC, TC, and C content. In Vineyard B, the differences were slightly more moderate, with variations in pH, EC, TC, and C content across different profiles, but not as pronounced as in Vineyard A.

Vineyard C:

Soil pH in Vineyard C fell within the range of 8.09 to 8.83, indicating alkaline soil conditions. Particularly, HZ1 showed an average pH value of 8.35, HZ2 had 8.29, 8.42 in HZ3, and 8.45 in HZ4. The average EC values were 156.7, 180.7, 157.2, and 151.6 mS/cm, respectively, in the 4 identified HZs, with HZ2 having the highest EC value and HZ4 the lowest. The AVs of TC ranged from 127.1 to 117.3 g/kg in HZ1 and HZ2 and 90.3 and 366.5 g/kg in HZ3 and HZ4, respectively, the lowest and highest value of the entire vineyard C. Finally, the C content was 7.16 and 8.27 g/kg in HZ1 and HZ2 and 4.70 and 3.10 g/kg in HZ3 and HZ4. HZ3 had the lowest average TC value, while HZ4 had the highest value. C content was highest in HZ2 and lowest in HZ4. The pH values were relatively close, with HZ2 having the lowest pH and HZ4 having the highest.

**5.3 Grape maturation indices**

The results of the analysis of the main oenological parameters on technological maturation at harvest time for the vintages 2021 and 2022 in Vineyards A, B, and C are here reported.

Vineyard A:

* In both 2021 and 2022, the weight of 50 berries had the highest values in different HZs. In 2021, the highest values were observed in HZ3 (125.4 g) and HZ4 (119.0 g), while in 2022, the highest values were in HZ4 (130.9 g) and HZ5 (125.2 g).
* When comparing the two vintages, the 2022 vintage displayed slightly higher °Brix (24.3 in HZ1 and 24.6 in HZ2), higher pH (3.21 in HZ1, HZ3 and HZ5), and slightly lower TA (6.99 g/L) values compared to the 2021 vintage. It is also interesting to observe that there is a reverse trend in terms of °Brix in HZ1 and HZ2 comparing 2021 and 2022 values, 22.7 and 19.5 respectively in 2021, which are the lowest values in Vineyard A, 24.3 and 24.6 respectively in 2022, which are the highest values in Vineyard A.

Vineyard B:

* The differences recorded in various areas within Vineyard B remained in line between the two years (2021 and 2022).
* °Brix values were higher in HZ1 (25.1 in 2021 and 23.2 in 2022) and HZ2 (22.8 in 2021 and 23.5 in 2022), followed by HZ5 (23 in 2021 and 22.7 in 2022). The pH values were lower in HZ1 (2.99) and in HZ2 (2.97) in 2021 vintage and in HZ1 (2.98), HZ4 (3.00) and HZ2 (3.02) in 2022 vintage. TA values were higher in HZ1 in both vintages 2021 and 2022 (10.05 and 9.88 g/L respectively). Regarding the 50 berries weight, the lowest values were in HZ2 and HZ4 in both vintages (92.7 g in 2021 and 86.5 g in 2022 in HZ2, 99.4 g in 2021 and 100.6 g in 2022 in HZ4). HZ1 showed the highest values in 2021 (102.4 g), while in 2022 HZ1 (105.5 g) followed HZ5 (109.4 g).

Vineyard C:

* In Vineyard C, HZ3 and HZ4 exhibited the highest °Brix values (25.7 and 24.1 in 2021, 25.1 and 25.9 in 2022), indicating potentially higher sugar content in these areas.
* HZ1 and HZ2 in Vineyard C displayed the highest values for the weight of 50 berries (91.7 and 96 g in 2021, and 119.9 and 115.3 g in 2022), suggesting larger berries in these HZs. TA show the highest values in HZ2 and HZ3 (9.84 and 9.45 g/L) in 2021, and in HZ1 and HZ2 (11.27 and 9.41 g/L) in 2022.

These findings highlighted the variations in oenological parameters within different areas of each vineyard and the differences between the two vintages. Vineyard A showed differences in the weight of 50 berries between HZs and slight variations in °Brix, pH, and titratable acidity between the two years. Vineyard B exhibited quite high differences of parameters across HZs and years. Vineyard C displayed variations in °Brix and berry weight between HZs for both years.

**5.4 Grape phenolic profile**

The phenolic profile of the grapes in Vineyard A, B and C for the vintages of 2021 and 2022, was assessed to determine the extractability potential of the phenolic compounds. Additionally, certain parameters were measured to evaluate the phenolic content in different vineyard HZs. Here is a summary of the findings for each vineyard:

Vineyard A:

In 2021 vintage, HZ1 exhibited the highest values of CI (13.89), Tot Ant (1014.90 mg/kg ME), and most of native anthocyanins (delf-3mg 60.57 mg/kg ME, pet-3mg 79.91 mg/kg ME, malv-3mg 709.89 mg/kg ME). Additionally, BSA Tannins (553.13 mg/kg CE) and IRPs (1224.87 mg/kg CE) were also highest in this HZ. These results indicate that HZ1 had the highest concentration of phenolic compounds and the greatest extractability potential among all the HZs in Vineyard A. HZ2 had the lowest values of phenolic parameters compared to the other HZs in Vineyard A (CI 8.82, Tot Ant 595.96 mg/kg ME, delf-3mg 21.29 mg/kg ME, cian-3mg 2.33 mg/kg ME, pet-3mg 31.74 mg/kg ME, peon-3mg 22.89 mg/kg ME, malv-3mg 421.42 mg/kg ME, IRPs 691.19 mg/kg CE). HZ3 showed similarities to HZ4 in terms of phenolic profile. In detail, they did not have the highest values but shared some similarities in phenolic profile.

In vintage 2022, HZ1 and HZ2 tended to have higher values compared to the other HZs in Vineyard A (CI 12.63 and 13.84, Tot Ant 706.94 and 692.28 mg/kg ME, delf-3mg 47.60 and 42.43 mg/kg ME, cian-3mg 7.12 and 6.95 mg/kg ME, pet-3mg 60.23 and 55.65 mg/kg ME, peon-3mg 46.03 and 48.67 mg/kg ME, malv-3mg 457.13 and 448.75 mg/kg ME).

In contrast to the previous vintage, HZ4 displayed the lowest values in terms of phenolic profile parameters (CI 9.40, Tot Ant 463.51 mg/kg ME, delf-3mg 21.33 mg/kg ME, cian-3mg 4.65 mg/kg ME, pet-3mg 25.58 mg/kg ME, malv-3mg 306.78 mg/kg ME, BSA Tannins 357.32 mg/kg CE and IRPs 741.83 mg/kg CE).

The findings suggest that there may be variations in the phenolic profiles of the grapes between vintages. Since HZ1 demonstrated higher values and extractability potential, the relative differences between the HZs differed in the two vintages.

Vineyard B:

In both 2021 and 2022 vintages, HZ1 and HZ2 exhibit the highest values for various phenolic parameters, including CI (15.32 and 13.16 in 2021, 15.33 and 15.33 in 2022, respectively), Tot Ant (980.42 and 1010.88 mg/kg ME in 2021, 962.59 and 1029.95 mg/kg ME in 2022) and all native anthocyanins (delf-3mg: 86.19 and 72.84 mg/kg ME in 2021, 86.52 and 94.40 mg/kg ME in 2022, cian-3mg: 11.31 and 7.09 mg/kg ME in 2021, 11.19 and 9.97 mg/kg ME in 2022, pet-3mg: 101.12 and 91.58 mg/kg ME in 2021, 101.05 and 107.53 mg/kg ME in 2022). BSA Tannins and IRPs also demonstrate higher values in these HZs compared to the rest of Vineyard B.

On the other hand, HZ3 consistently shows the lowest values for the entire anthocyanin component (CI 12.21 in 2021 and 11.49 in 2022, Tot Ant 730.10 g/kg ME and 686.97 g/kg ME in 2022 and native anthocyanins) in both 2021 and 2022 vintages. However, it’s worth noting that Area 3 does not exhibit the lowest values for BSA Tannins IRPs, which suggests that the phenolic profile in terms of tannins and IRPs may differ from that of anthocyanins.

The observed detachment of HZ1 and HZ2 from the rest of the areas in terms of higher phenolic content indicates their potential for greater extractability of phenolic compounds. Conversely, HZ3 consistently displays lower values for anthocyanins, suggesting lower concentrations and extractability potential for these compounds.

Vineyard C:

In both 2021 and 2022 vintages, HZ3 and HZ4 consistently exhibit the highest values for CI (17.85 and 16.33 in 2021, 15.96 and 12.87 in 2022) and Tot Ant (1056.13 and 914.63 mg/kg ME in 2021, 795.78 and 667.98 mg/kg ME in 2022). On the other hand, HZ1 and HZ2 consistently show lower and more similar values for all components of the anthocyanin profile (CI, Tot Ant and native anthocyanins), as well as for BSA tannins and IRPs in both the 2021 and 2022 vintages. This suggests that these HZs have lower concentrations and extractability potential for phenolic compounds compared to HZ3 and HZ4.

**5.6 Wine**

The analyses of wines from Vineyard A and Vineyard B in the 2021 and 2022 vintages showed clear differences in enological parameters, as well as for the chromatic profile. These differences include alcohol content, pH, TA, and chromatic profile (CI, Tot Ant, tannins BSA, IRPs). However, comparing the vintages revealed that the variations in the chromatic profile were mainly due to the different stages of wine aging during analysis. Wine aging plays a crucial role in modifying color and phenolic compounds. As wines age, phenolic compounds undergo reactions affecting CI, HUE, and stability. Aging allows integration and polymerization of tannins, resulting in color stability and complexity. Phenolic compounds can interact with oxygen and other components, leading to pigment formation. Considering the wines' aging stage is important when comparing vintages and interpreting chromatic profile differences. These findings provided insights into wine evolution over time and helps understand how soil zones in Vineyards A and B contribute to phenolic composition and chromatic characteristics during different aging stages.

# **6. Conclusions and Future Perspectives**

The obtained results indicate that among the identified HZs, those characterized by lower soil carbon content, higher EC, higher soil pH, and higher total carbonates revealed that were associated to favorable grape enological characteristics. These HZs displayed trends such as lower grape weight, higher °Brix, CI, Tot Ant, BSA tannins and IRPs values. These conditions suggest moderate vine stress contributing to the synthesis of desirable extractable phenolic compounds. In conclusion the differences recorded in HZs in terms of soil properties yield grapes with better enological attributes, including the chromatic profile and the phenolic composition, increasing the aging potential in wines.

Then, this approach revealed effective for the identification of vineyard areas characterized by different enological properties and elemental profile, giving a contribution in the assessment of precision viticulture methodologies aimed to wine quality improvement. Indeed, acquisition of knowledge on the enological variability at vineyard scale represent an additional possibility for winemakers to tailor their management strategies according to the specific soil characteristics.

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