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The variable rate fertilization in a highly productive vineyard of cv. Trebbiano romagnolo (*Vitis vinifera* L.) may reduce nitrogen application and vigor variability without yield loss.

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Abstract.

The site-specific management of the vineyard cultural practices may reduce the spatial variability of vine vigor, contributing to achieve the desired yield and grape composition. In this framework, variable rate fertilization may effectively contribute to reduce the different availability of mineral nutrients between different areas of the vineyard, and so achieving the vine's aforementioned performances.

The present study was aimed to apply a variable rate fertilization in a highly productive vineyard of the fertile Po Valley (Italy) and to evaluate the effects on the spatial variability of vigor.

The trial was conducted over two consecutive seasons (2018-2019) in a not irrigated, 3 ha vineyard of cv. Trebbiano romagnolo, trained to GDC and grafted onto SO4. During the summer of both years, vine vigor was mapped with a quad equipped with two GreenSeeker sensors in order to calculate the normalized difference vegetation index (NDVI); simultaneously, soil apparent electrical conductivity (ECa) was measured by the TopSoil Mapper sensor. Successively, clusters were harvested and berries were sampled according to a prearranged grid for georeferencing yield components and quality parameters. Then, maps of vigor, yield and soluble solid concentration were created. At the beginning of the vegetative growth of 2019, the variable rate fertilization was performed according to a prescription map based on NDVI data of 2018.

The NDVI map of 2018 discriminated two zones with different levels of vigor (high, NDVI ≥ 0.73) and medium, 0.55 ≤ NDVI < 0.73), and showed spots scattered in the vineyard with NDVI lower than 0.55, corresponding to dead vines or vines severely affected by "Flavescence dorée" and "Esca disease". On the other hand, only minor differences were found in soil apparent electrical conductivity, and it was not possible to delineate a map with zones characterized by different levels based on this parameter.

Harvest data of 2018 showed that in the zones with higher vigor, vines were more productive that those characterized by medium vigor. As expected, high yield was correlated with low sugar concentration and high titratable acidity. The variable rate fertilization performed in spring of 2019 consisted in the application of 30 kg/ha of N in the high vigor zones, 60 kg/ha of N in the zones

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with medium vigor and no N application in the areas with NDVI < 0.55. This operation allowed us to save 15 kg/ha of nitrogen compared to farm fertilization and contributed to reduce the spatial variability of vigor. In fact, the 2019 NDVI map showed that the area of the higher vigor zones increased over the previous year. Harvest data of 2019 showed an overall increase of yield and confirmed the relations between yield and berry composition observed in 2018.
Those results show that variable rate fertilization may be adopted also in highly productive vineyards to reduce spatial variability of vigor without negative consequences on yield. Then, it is expected that a large-scale adoption of this technique would generate a remarkable reduction of fertilizer with beneficial consequences on the environment.

Keywords.
NDVI, precision viticulture, spatial variability, sustainable management, vigor, yield

Introduction

The precise management of the vineyard, based on the variable rate application of some cultural techniques, may reduce the spatial variability of the vegetative and productive performances of the vines, contributing to reach the desired yield and grape quality, and reducing agronomical inputs (Bramley and Hamilton, 2004).

The spatial variability of vine behavior is usually caused by the heterogeneity of soil characteristics (Arnó et al., 2012; Trought et al., 2008), some of which are unalterable (e.g. soil texture) while others may be changed with cultural techniques (e.g. concentration of organic matter and mineral nutrients). Therefore, mapping the spatial variability of the vegetative and productive traits of the vines is necessary to understand their specific requirements, and in turn to adopt a precise management of the vineyard.

In the last decades, the rapid development of the sensors has been enhancing the building of NDVI (Normalized Difference Vegetation Index) maps, which are useful to identify the variability of vine vigor, a characteristic which is usually well correlated with yield and grape quality (Gatti et al., 2017). Thus, NDVI maps enables the variable rate application (VRA) of some management techniques that allow to reduce the spatial variability of the vegetative and yielding characteristics and to achieve the preset enological target (Gatti et al., 2018 e 2019).

Fertilization and irrigation are the techniques that influence the vine growth more than others. Unfortunately, it is still not possible to easily apply a VR irrigation in the vineyards but in the last decade the VR fertilizer spreaders have been developed and they are able to apply different amounts of fertilizers in a given vineyard, following the instruction of the prescription map. Furthermore, the VR fertilization may ameliorate the sustainability of grapevine cultivation, because the reduction of the waste of fertilizers has positive effects both from the economic and the environmental point of view.

Considering this emerging issue, this study aimed to realize and test an approach for VR fertilization using proximal sensors in a vineyard of cv. Trebbiano romagnolo. This white berry variety is cultivated on about 12000 hectares, mainly in the flat land of the Emilia-Romagna Region, where the target is to reach high yield levels with quality characteristics suitable for the production of white popular wines.

Materials and methods

The trial was conducted during 2018 and 2019 growing seasons, in a not-irrigated vineyard of cv. Trebbiano romagnolo (*Vitis vinifera* L.), clone TR 3T grafted onto SO4 rootstock, planted in 1997. Vines were trained to GDC (Geneva Double Curtain) and spaced 4 m between the rows and 1 m within the row. The vineyard (3 ha) is located in the flat and fertile Po Valley (north of Italy) and the floor management was conducted as follow: the inter-row was covered with spontaneous weeds which were mowed periodically to avoid excessive evapotranspiration, and soil tillage was performed in the under-row by an offset-type cultivator, twice per year. Vines were sprayed periodically to control downy mildew, powdery mildew, and insects according to Emilia-Romagna Region standard practices. The target of this vineyard was to reach high yields for the production of white popular wines.

During the summer of the two-year trial, the active radiometer GreenSeeker (GS) (NTech Industries, Inc., Ukiah, CA, USA), was used to measure canopy reflectance in the red (R_{RED}) (650±10 nm) and NIR (R_{NIR}) (770 ±15 nm) band, and calculate normalized difference vegetation index (NDVI) according to the formula: NDVI = $(R_{NIR}-R_{RED})/(R_{NIR}+R_{RED})$ providing an indication of crop health and vigour (Tucker, 1979).

The survey was carried out speedily by installing on a quad a pair of superposed radiometers at a height from the ground of 1.37 m and 1.64 m respectively, which allowed to intercept a vegetative layer of 0.40 m. The vehicle was equipped with a positioning system consisting of a receiver with an integrated GNSS antenna, model STONEX® S8 PLUS, and an RTK (Real-Time Kinematic) correction system with centimetre-level accuracy.

Simultaneously with NDVI acquirement, the Geoprospectors® Top Soil Mapper electromagnetic induction sensor, mounted on the same vehicle, measured the soil apparent electrical conductivity (ECa) at four levels of depth (0-0.25 m, 0-0.4 m, 0-0.6 m, 0-0.8 m).

At harvest (13 September 2018 and 25 September 2019), yield components (number and weight of clusters) and quality parameters (soluble solids concentration, pH and titratable acidity) were measured on 20 groups of 6 consecutive vines each, following a prearranged grid for georeferencing the values covering the whole vineyard. Soluble solids concentration was analyzed using a temperature-compensating Maselli R50 refractometer (Maselli Misure), while pH and titratable acidity with a Crison Titrator (Crison Instruments).

During the growing seasons, dead vines and those affected by 'Flavescence dorée' or 'Esca desease' were georeferenced by the GPS (S42H Stonex).

NDVI values were analysed using geostatistics (ArcGIS version 10.3) by computing the best fit semi-variogram model among the circular, spherical, exponential, Gaussian, and stable models (Ali et al., 2022) and interpolated by simple kriging (SK) with a 1x1 m grid size. In detail, the NDVI raster layers were intersected with a 1x1 m point grid obtaining a dataset of regular points with NDVI attributes. Finally, the position of dead and diseased plants was also associated. The prescription map for the VR fertilization was based on the NDVI values of 2018 and three classes were identified corresponding to three levels of vigor.

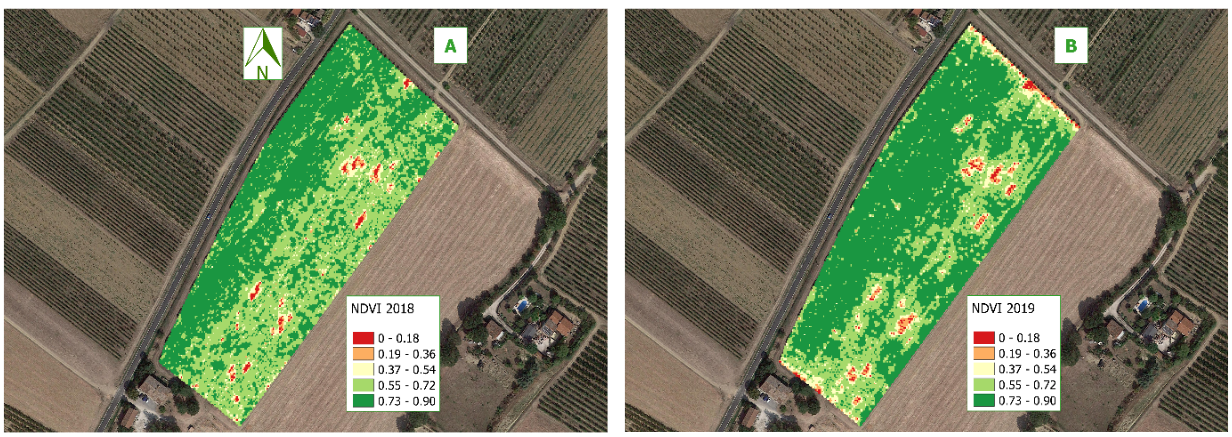
On March of 2019, the vineyard was uniformly fertilized with a complex NPK mineral fertilizer which provided 40 kg/ha of nitrogen. In May 2019, the VR fertilization was performed with a centrifugal fertilizer spreader Kuhn MDS 12.1 equipped with a metric measurement system connected to a STONEX S8 Plus GPS receiver with automatic control of the distributed dose. The prescription map was uploaded on the distribution system to allow the spreader to apply different amounts of fertilizer according to the position in the vineyard. The doses of nitrogen applied using urea were: i) 30 kg/ ha in the zones with NDVI ≥ 0.73 to maintain the vegetative and productive behavior of the vines and to reduce the waste of fertilizer; ii) 60 kg/ha in the zone with 0.55 ≤ NDVI < 0.73 to enhance the growth and the yielding capacity of the vines; iii) no urea application where NDVI < 0.55, to avoid the waste of fertilizer.

Results and discussion

NDVI map of 2018

The NDVI map of 2018 (Fig. 1A) showed some interesting aspects regarding the level of vigor and its spatial variability. The class of 'high' vigor (NDVI ≥ 0.73) and 'medium' vigor (0.55 ≤ NDVI < 0.73) represented about the 98% of the vineyard area, and only the remaining 2% showed NDVI lower than 0.55. The georeferencing of dead vines and those affected by 'Flavescence dorée' or 'Esca desease' allowed us to associate the NDVI values lower than 0.55 to the small areas in which those vines were found. Therefore, considering that the vineyard was planted in 1997, it appeared that only a small portion was not productive and that the remaining area was characterized by vines with satisfactory level of vigor. Regarding this last issue, it should be taken into consideration that the vineyard was cultivated in a fertile soil, in which high doses of fertilizers had been previously applied to maintain the high yielding standards. Moreover, it can be noted that the highest level of vigor prevails in the north-west part of the vineyard.

The data of soil resistivity that were acquired simultaneously to those of NDVI, showed only minor differences in the vineyard and so it was not possible to identify zones characterized by different levels of this parameter. This result suggests that there should be no substantial difference of soil water content in the vineyard and that the differences of vigor may be more dependent on differences on the concentration of the nutrients in the soil (Filippetti et al., 2013).

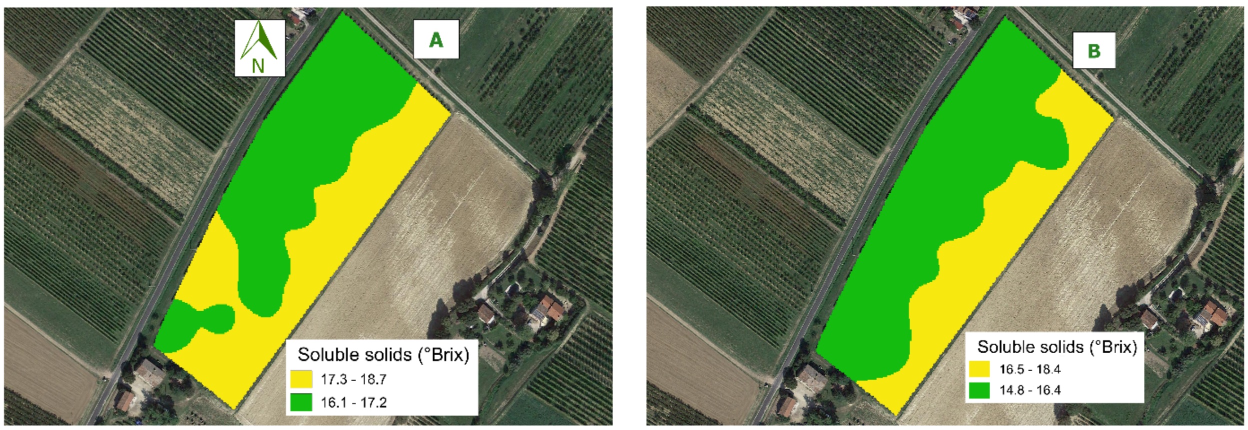


Figures 1. NDVI maps of 2018 (A) and 2019 (B).

Harvest of 2018

The harvest of 2018, conducted following the pre-arranged grid, showed that yield was higher in the part of the vineyard where the 'high' vigor prevailed (Fig. 2A), and in the average it resulted equal to 10.4 kg/vine corresponding to 26.8 t/ha. Conversely, lower yield was associated to the zones where the 'medium' vigor prevailed, and corresponded to 7,5 kg/vine (18.7 t/ha). As expected, in the more productive zones (Fig. 3A), the soluble solids concentration was lower (17.0 °Brix) than that of the less productive ones (17.7 °Brix).

Figures 2. Yield maps of 2018 (A) and 2019 (B).



Figures 3. Soluble solids concentration maps of 2018 (A) and 2019 (B).

Prescription map for VR fertilization

The prescription map used for the VR fertilization performed on May 2019 (Fig. 4), was based on the NDVI data acquired in 2018. This operation, that lowered the dose of nitrogen applied in 'high' vigor zones and avoided the application of the fertilizer on the dead vines and those affected by 'Flavescence dorée' or 'Esca desease', allowed to save 15 kg/ha of nitrogen, respect the standard fertilization which consisted in a uniform application of 60 kg/ha of nitrogen.

NDVI map of 2019

The vigor map of 2019 (Fig. 1B) showed that the area with 'high' vigor increased compared to the previous year and consequently decreased that of the 'medium' vigor, indicating the tendency toward the reduction of the spatial variability (Fig. 5). This result is consistent with the reduction of the coefficient of variance of measured NDVI data (21.0% in 2018 vs 15.2% in 2019).
Regarding the geostatistical analysis, the pattern of NDVI spatial distribution indicates that the stable model and the exponential model were the best fitting in 2018 and 2019, respectively. The semi-variogram parameter “sill”, that decreased from 1.02 in 2018 to 0.95 in 2019, showed a stronger spatial dependence among dataset in 2018 NDVI as compared to 2019, confirming the spatial variability reduction with time.

Figure 4. Prescription map used for VR fertilization carried out in 2019.

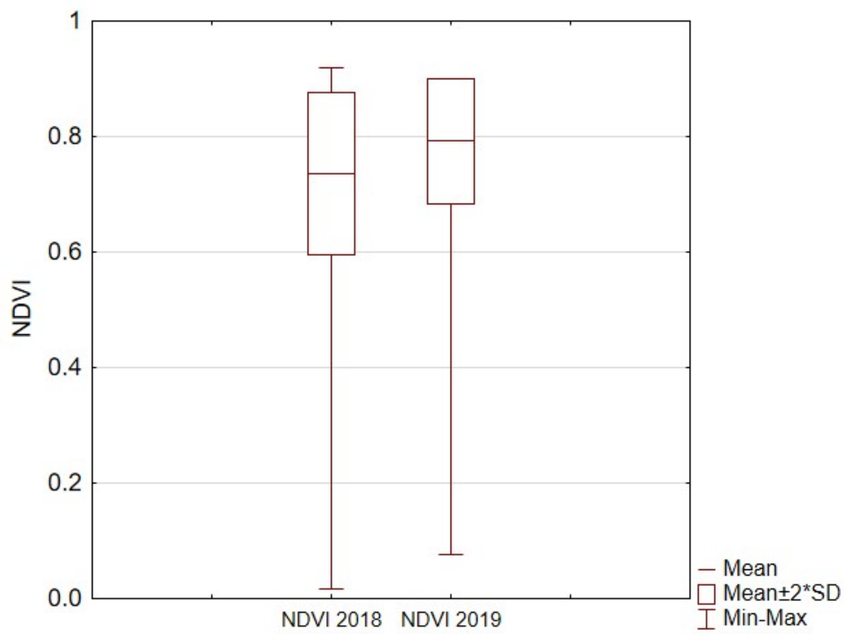


Figure 5. Box plot of NDVI values measured on 2018 and 2019.

The reduction of the spatial variability of the vigor between 2018 and 2019 was probably due to the different amounts of nitrogen applied in May with the VR fertilization and to the abundant precipitation that were well distributed during the growing phases of the shoots (218 mm during May and June 2019), that might have optimized the uptake of the higher quantities of nitrogen applied in the zones with 'medium' vigor.

Harvest of 2019

The harvest of 2019 was characterized by the overall increase of yield compared to the previous year, in fact in the areas where the 'high' vigor prevailed (Fig. 2B), the productivity reached 12.8 kg/vine (31.8 t/ha), while in those where the 'medium' vigor prevailed, resulted equal to 10.5 kg/vine (26.4 t/ha). Coherently with the higher yield levels of 2019, the concentrations of soluble solids resulted lower than the previous year (Fig. 3B) and differences appeared between the two vigor zones (17.1 vs 15.9 °Brix).

The overall yield increase noted in 2019 was favored by the higher number of clusters per vine compared to that of 2018 (data not reported), and the good amount of precipitation (422 mm) which resulted well distributed in the period April-September 2019. Considering that inflorescence initiation begins in the previous year of flowers formation (May, 2000), it appears clear that the VR fertilization performed in May 2019, cannot have influenced the yield and sugar spatial variability of the same year. Nevertheless, the reduction of the spatial variability of the vigor might contribute to lower the variability of yield and quality parameters, but it is important to repeat the VR fertilization in the following growing seasons because perennial crops, such as vineyard and orchards, needs at least 3-4 years to show stable results (Davenport et al., 2003).

Conclusion

The experiences conducted in this trial allowed to define a protocol for the VR fertilization based on the spatial variability of the vine vigor which was estimated with proximal sensors. Then, the zones characterized by different vigor were evidenced even if the trial was conducted in a vineyard cultivated in a flat and fertile soil. Moreover, it was possible to identify the small areas where the vines were dead or affected by diseases that usually cause the death of the plant in few years.

Then, the goal to reduce the spatial variability of the vigor was achieved by the VR fertilization, because this technique contributed to increase the vigor where necessary and maintained high levels of vigor where it was already high, even if the amount of nitrogen was lower than that usually applied. Moreover, the high yielding capacity was maintained and the quality parameters resulted appropriate for the enological target.

Finally, considering the costs to benefit ratio, it appears clear that saving 15 kg/ha of nitrogen does not cover the costs incurred to acquire and process the NDVI data, and to realize the VR fertilization. Despite that, some interesting perspectives should be taken into consideration. First of all, the use of complex and specific fertilizers would generate higher saving than that generated using urea (as done in this experiment). Then, the reduction of the fertilizer applied in the vineyard may reduce the leaching of nitrates to groundwater with a positive environmental impact, in particular if it is considered that the cultivation of cv. Trebbiano romagnolo for the production of popular wines covers about 12000 ha in the area where the trial was carried out. Finally, understanding the variability of the vigor might allow to adopt the variable rate application of other management techniques that may contribute to achieve the productive and qualitative objectives with less agronomical inputs.

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