Effects of natural clinoptilolite on physiology, water stress, sugar, and anthocyanin content in Sanforte (Vitis vinifera L.) young vineyard

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Abstract

In the Mediterranea area, major effects of climate change are a modification in rainfall patterns, an increase in temperature with an intensity in tropical nights, and an increase in incoming radiations, especially UV-Bs. Despite the various adaptation strategies, grapevines are sensitive to altered climatic conditions. This paper aims to assess the benefits of applying a new sustainable product to the soil that can implement farmers’ resources to adapt to this changing situation. Zeowine was realized by combining the properties of zeolite, which has excellent potential in many sectors such as in agriculture, with the organic substance of a compost obtained on a company scale from the reuse of waste processing grapes, pomace and stalks. The effects of two different soil management (Zeowine, 30 t/ha dose and Compost, 20 t/ha dose) on vine physiology and berry compositions in Sanforte grapevines (plantation) were studied during the 2019–2020–2021 growing seasons in the San Miniato area, Italy. The following physiological parameters of grapevines were measured: leaf gas exchange, leaf temperature, stem water potential and chlorophyll fluorescence. The results showed that Z increased single leaf photosynthesis, reduced leaf temperature and water stress. In addition, phenolic and technological parameters were studied. The Z-treated vines had higher sugar content and total and extractable anthocyanin content as well as berry weight. These results suggested that the application of zeolites added to compost in the vineyard to the soil can be a valid tool to mitigate the effects of climate change.

Introduction

Climate change can affect agriculture in several aspects (Cline, 2008). An increase in intensity and frequency of many extreme climate events, a decrease in rainfall and frequent heat waves can be identified such as characteristics of climate change (Houghton, 2005; Gourdji et al., 2013). In fact, the global climate scenario will be distinguished by a rise in greenhouse gases amount, a rise in temperature and changes in the precipitation diagrams (Marin et al., 2021). With excessive increase temperatures, warming leads to reduce crop yields because plants increase the speed of their development, producing less in the process (Hedhly et al., 2009; Chen et al., 2020). On the one hand, although the increase of atmospheric carbon dioxide (CO2) concentration can enhance photosynthesis, as a carbon source and reproduction, provided the original article is properly cited.
It is in this context that the use of zeolite in soil management assumes greater importance (Ramesh and Reddy, 2011). Zeolite [Greek words ζέω, ‘boil’ and λίθος, ‘stone’, ‘boiling stones’ (Polat et al., 2004)], are interesting and versatile minerals that are vital for several ranges of industries due to their particular and unique chemical and structural properties (Van Speybroeck et al., 2015). They are aluminosilicate solids, natural or synthetic origin, bearing a negatively charged framework of micropores into which molecules may be adsorbed for environmental decontamination and to catalyse chemical reactions (Bacakova et al., 2018).

Due to their ability to perform cation exchange, zeolite applications were found in various industries, such as in the pharmaceutical industry, petrochemical industry (Rhodes, 2010; Bish and Ming, 2018). Zeolites have many properties, some of these are of interest for agricultural purposes: high CEC, high water holding capacity in the free channels, and high adsorption capacity (Hedström, 2001). In agriculture, some of the important applications are water treatment (Margeta et al., 2013), gas adsorption (Mofarahi and Gholiipour, 2014), aquaculture (Nomura et al., 2017), animal husbandry (Ilc et al., 2011), absorption of heavy metals (Tahervand and Jalali, 2017) and also for odour control (Halim et al., 2010). Zeolites can also absorb up to 55% water, later this water is used by the plants for their metabolic activities (Pisarovic et al., 2003). In grapevine, foliar applications of chabasite-rich zeolites were able to control simultaneously grey mould, sour rot and grapevine moth and improve the compositional and organoleptic characteristics: 20.2% silt, 27.9% clay and 51.8% sand; organic matter 1.79% once a day on the following dates: flowering (9 July 2019, 2 July 2020, 28 June 2021), while grape sampling was conducted in the 2020 season (third year of planting of the vineyard) and 2021 (fourth year of planting of the vineyard) as 2019 was without production.

### Materials and methods

#### Study region, climatic conditions, experimental design and settings

This study was carried out in the viticultural Chianti area, in the San Miniato county (PI) (coordinates Lat. 43°40′55.1″N and Long. 10°53′13.8″E), Tuscany, Italy, located at an elevation of 190 m a.s.l. facing North-East exposure, at the Cosimo Maria Masini estate. The San Miniato climate is Mediterranean, semi-arid, with a mean annual precipitation of 800 mm and a mean annual temperature of 14.5°C. According to Italian legislation, a decree of the President of the Republic n. 412 of 26 August 1993 (Table 1) the climatic classification of the municipality of San Miniato is D, 1513 degree days (GG).

An automated weather station (Ecotech, Germany) located at 80 metres from the vineyard, was used to record total rainfall (mm) and maximum, mean and minimum air temperature (°C). Trials were conducted during 2019, 2020 and 2021, while grape sampling was conducted in the 2020 season (third year of planting of the vineyard) and 2021 (fourth year of planting of the vineyard) as 2019 was without production.

#### Stomatal conductance and leaf temperature, net photosynthesis and water use efficiency, midday stem water potential, leaf chlorophyll fluorescence and content

During three seasons, from flowering to maturity, between 10 and 12 a.m., leaf temperature and leaf gas exchange (stomatal conductance (gs), transpiration rate (E) and net photosynthesis (Pn)) was measured using Ciras 3, a portable infrared gas analyser (PP Systems, Amesbury, MA, USA), on 12 healthy and fully developed leaves per treatment, in the median portion of a primary shoot (12 replicates, one each tagged vine). Measurements were taken once a day on the following dates: flowering (9 July 2019, 2 July 2020, 28 June 2021), fruit set (17 July 2019, 13 July 2020, 5 July 2021), while grape sampling was conducted in the 2020 season (third year of planting of the vineyard) and 2021 (fourth year of planting of the vineyard) as 2019 was without production.

| Climatic zones | From (GG) | To (GG) |
|----------------|-----------|---------|
| A              | 0         | 600     |
| B              | 601       | 900     |
| C              | 901       | 1400    |
| D              | 1401      | 2100    |
| E              | 2101      | 3000    |
| F              | 3001      | 4000    |

From the two central rows of each block, two homogeneous vines (total 12 vines per soil treatment) were randomly tagged for leaf gas exchange, water potential and grape composition assessments. Ecophysiological measurements were carried out during the three vegetative seasons (2019–2020–2021), while grape sampling was conducted in the 2020 season (third year of planting of the vineyard) as 2019 was without production.

#### Table 1. Climatic zones of the Italian territory according to the degree days (GG)

| Climatic zones | From (GG) | To (GG) |
|----------------|-----------|---------|
| A              | 0         | 600     |
| B              | 601       | 900     |
| C              | 901       | 1400    |
| D              | 1401      | 2100    |
| E              | 2101      | 3000    |
| F              | 3001      | 4000    |
July 2021), pre veraison (22 July 2019, 21 July 2020, 12 July 2021), veraison (6 August 2019, 1 August 2020, 29 July 2021), mid maturation (19 August 2019, 17 August 2020, 18 August 2021), full maturation (26 August 2019, 3 September 2020, 31 August 2021). The photosynthesis/transpiration ratio, extrinsic water use efficiency (eWUE), was calculated. Setting the leaf chamber flow under the same conditions as Cataldo et al. (2021b) measurements were performed: saturating photosynthetic photon flux of 1300 μmol/m²s, ambient CO₂ concentration ∼400 ppm and ambient temperature.

Using a pressure chamber (model 600, PMS Instrument Co., Albany, OR, USA), midday-stem water potential (Ψstem, MPa) of dark-adapted leaves (over a 60-min period) was determined on 10 fully expanded leaves per treatment (Ritchie and Hinckley, 1975). Measurements were conducted between 12 noon and 1:00 p.m., from flowering to the ripening phase, in the median portion of a primary shoot (10 replicates, one each tagged vine). Measurements were taken once a day on the following dates: flowering (9 July 2019, 2 July 2020, 28 June 2021), fruit set (17 July 2019, 13 July 2020, 5 July 2021), pre veraison (22 July 2019, 21 July 2020, 12 July 2021), veraison (6 August 2019, 1 August 2020, 29 July 2021), mid maturation (19 August 2019, 17 August 2020, 18 August 2021), full maturation (26 August 2019, 3 September 2020, 31 August 2021).

Fig. 1. Colour online. Vineyard Microclimate. Monthly total rainfall (mm) and mean, maximum, minimum temperature (°C) of 2019, 2020 and 2021. The data refer to the following months: April 2019–December 2019 (91–335 DOY), January 2020–December 2020 (1–336 DOY) and January 2021–September 2021 (1–244 DOY).

In the hottest and driest period, from pre-veraison to the ripening, using Handy-PEA® tool (Hansatech Instruments, UK), Chlorophyll a fluorescence transient of dark-adapted leaves was recorded with a saturating flash of actinic light at 3000 μmol/m²s for 1 s. Briefly, the maximum quantum yield of photosystem II (PSII) was calculated as the ratio \( F_v/F_m = (F_m - F_0)/F_m \) where \( F_v \) represents the variable fluorescence and \( F_m \) represents the maximal fluorescence of dark-adapted (over a 30-min period) leaves (Maxwell and Johnson, 2000).

Measurements were taken once a day on the following dates on 12 healthy and fully developed leaves per treatment, in the median portion of a primary shoot (12 replicates, one each tagged vine): pre veraison (22 July 2019, 21 July 2020, 12 July 2021), veraison (6 August 2019, 3 August 2020, 29 July 2021), mid maturation (19 August 2019, 14 August 2020, 18 August 2021), full maturation (26 August 2019, 3 September 2020, 31 August 2021).

A 502 SPAD device (Konica Minolta Inc., Japan) was used to measure chlorophyll content in leaves. Measurements were taken once a day on the following dates on 12 healthy and fully developed leaves per treatment, in the median portion of a primary shoot (12 replicates, one each tagged vine): pre veraison (22 July 2019, 21 July 2020, 12 July 2021), veraison (6 August 2019, 3 August 2020, 29 July 2021), mid maturation (19 August 2019, 14 August 2020, 18 August 2021), full maturation (26 August 2019, 3 September 2020, 31 August 2021).
During 2020–2021 seasons, from veraison to harvest (3 August 2020, 17 August 2020, 3 September 2020, 8 September 2020 and 29 July 2021, 18 August 2021, 31 August 2021, 10 September 2021), a 100-berry sample was collected mixing berries from the tagged vines of each block of both Zeowine and...

**Berry composition**

During 2020–2021 seasons, from veraison to harvest (3 August 2020, 17 August 2020, 3 September 2020, 8 September 2020 and 29 July 2021, 18 August 2021, 31 August 2021, 10 September 2021), a 100-berry sample was collected mixing berries from the tagged vines of each block of both Zeowine and...
Compost vines (12 samples of 100-berry in total per treatment) to perform technological analyses and determine the optimal maturity level to harvest (ripening curves). Each sample was weighed with a digital scale (model ES2201, Artiglass, Due Carrare, PD, Italy) and immediately juiced. Sugar content (°Brix) was measured using a refractometer (PCE-Oe Inst., Lucca, Italy); pH was measured using a portable pH meter (PCE-Oe Inst., Lucca, Italy) and must g/L tartaric acid (titratable acidity) was determined on a 10 mL for each 100-berry sample by manual glass burette using 0.1 M NaOH to an endpoint of pH 7.0. Moreover, a duplicate 100-berry sample was picked mixing berries from the tagged vines of each block of both Zeowine and Compost vines (12 samples of 100-berry in total per treatment), was processed for phenolic maturity parameters, such as extractable and total polyphenols and anthocyanins (mg/l) (Ribéreau-Gayon et al., 2021) with the Yves-Glories method (Glories, 1984). Briefly, the samples were read with the spectrophotometer (Hitachi U-2000, Chiyoda, Japan) at 520 nm for anthocyanins and 280 nm for polyphenols. In addition, as described by the method, the following solutions were used: aqueous solution of tartaric acid at pH 3.2, solution of ethanol hydrochloride EtOHCl, 2% solution of HCl and an aqueous solution of SO2.

Statistical analysis

Data from each season 2019, 2020 and 2021 were separately analysed by means of one-way ANOVA with soil treatments as the main factor (P ≤ 0.05). In addition, mean values were separated by Fisher’s least significant difference (LSD). P value adjustment was performed with the Holm method (P ≤ 0.05). All statistical analyses were performed using R and RStudio (Boston, MA, USA) (Allaire, 2012).

Results

Vineyard microclimate

Climate resulted as typical of the Mediterranean region, although some differences in rainfall pattern were detected in the three
different years of research (Fig. 1). The 2019 year (657.8 mm rain/growing season) was characterized by an even distribution of rain especially during spring and autumn with a dry period in June and August. The 2020 year (454.6 mm rain/growing season) was characterized by an even distribution of rain especially autumn with a dry period in April and July. Whereas the 2021 year (458.2 mm rain/growing season) was characterized by an even distribution of rain especially autumn with a dry period in June and July. Maximum temperatures exceeded 35°C on the following days (Fig. 2): from 25 to 30 June 2019 (176–181 DOY), from 1 to 3 July 2019 (182–184 DOY), from 23 to 26 July 2019 (204–207 DOY), 11 and 12 August 2019 (223–224 DOY), from 30 July to 1 August 2020 (212–214 DOY), from 8 to 10 August 2020 (221–223 DOY) and 12 August 2020 (225 DOY), 7 July 2021 (188 DOY), 26 July 2021 (207 DOY) and from 11 to 15 August 2021 (223–227 DOY).

**Stomatal conductance and leaf temperature, net photosynthesis and water use efficiency, midday stem water potential, leaf chlorophyll fluorescence and content**

As reported in Figs 3(A)–(F), no significant differences were noted in chlorophyll content (maximum quantum yield of PSII) in leaves of *Vitis vinifera* between treatments (Zeowine and Compost), while chlorophyll a fluorescence reported differences especially in the warmer period (6–19 August 2019, 3 August 2020, 12 July 2021 and 18 August 2021).

On the hottest days, significant differences in physiological parameters (Pn and WUE) between Z and C during the three study seasons (2019, 2020 and 2021) were found; Zeowine showed higher rates of photosynthesis v. C treatment (Table 2).

Treatment C showed in all seasons, values of leaf temperature higher than treatment Z. On the hottest days, the Z treatment tended to record values of superior stomatal conductance (Fig. 4).

Significant differences in stem water potential between soil treatments were found (Fig. 5). Leaf water potential values reflect seasonal trends; peaks of increased water stress were recorded in July 2019, August 2020 and July/August 2021 after the driest and hottest months (June 2019, July 2020 and July 2021).

**Berry composition**

Table 3 shows the composition of Sanforte berries under two different soil management approaches in 2020 year (first year of production of the vineyard) and in 2021 year (second year of production of the vineyard) in terms of technological maturity. During the 2020 season, significant differences at full veraison, mid-maturation and harvest were noted in sugar content and during the 2021 season, significant differences at mid-maturation, full-maturation and harvest were noted in sugar content. Z had the highest values than C treatment. In the 2020 harvest, the C treatment detected higher acidity values, while in the 2021 harvest no difference was noted in acidity values.

As shown in Table 4, the greatest differences in phenolic maturity were found in the composition of extractable and total anthocyanins. As for the 2020 season, at full maturation and harvest, Z berries showed significantly higher extractable and total anthocyanin content compared to C berries. The lowest values in total

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Table 2. Physiological parameters

| Survey date | Pn (μmol CO₂/m² s) | eWUE (μmol CO₂/mmol H₂O) |
|-------------|------------------|--------------------------|
|             | Z                | C            | Z     | C            |
| 9 July 2019 | 5.85 ± 1.12a     | 4.91 ± 0.99a | 1.16 ± 0.31a | 1.05 ± 0.44a |
| 17 July 2019| 7.26 ± 1.37a     | 6.82 ± 1.52a | 1.48 ± 0.25a | 1.78 ± 0.12a |
| 22 July 2019| 7.32 ± 2.04a     | 5.71 ± 1.96b | 2.00 ± 0.69a | 1.82 ± 0.76a |
| 6 August 2019| 9.36 ± 1.75a   | 8.10 ± 1.23b | 2.54 ± 0.87a | 2.06 ± 0.59b |
| 19 August 2019| 8.22 ± 1.55b | 9.90 ± 0.97a | 2.13 ± 0.64b | 2.61 ± 0.43a |
| 26 August 2019| 9.72 ± 2.10a | 3.80 ± 0.87b | 2.51 ± 0.58a | 1.57 ± 0.32b |
| 2 July 2020   | 9.40 ± 2.23a     | 8.10 ± 1.76a | 2.29 ± 0.43a | 2.04 ± 0.22a |
| 13 July 2020  | 12.42 ± 2.34a   | 12.32 ± 2.80a | 3.42 ± 0.89a | 3.08 ± 0.91a |
| 21 July 2020  | 13.47 ± 2.99a    | 10.75 ± 2.55b | 3.04 ± 0.21a | 2.22 ± 0.65b |
| 1 August 2020 | 10.14 ± 2.67a    | 9.56 ± 1.71a | 2.06 ± 0.42a | 2.21 ± 0.23a |
| 17 August 2020| 11.99 ± 1.41a    | 5.60 ± 2.05b | 4.68 ± 0.99a | 3.47 ± 0.62b |
| 3 September 2020| 7.30 ± 1.77a  | 3.77 ± 1.45b | 2.52 ± 0.48a | 1.22 ± 0.30b |
| 28 June 2021  | 11.36 ± 3.20a    | 9.58 ± 2.58b | 5.79 ± 0.56a | 4.84 ± 0.21b |
| 5 June 2021   | 16.42 ± 4.60a    | 11.28 ± 3.67b | 5.29 ± 0.32b | 6.19 ± 0.80a |
| 12 July 2021  | 11.50 ± 2.43a    | 7.33 ± 1.31b | 1.37 ± 0.40a | 1.04 ± 0.12a |
| 29 July 2021  | 8.04 ± 2.50a     | 5.55 ± 2.42b | 1.47 ± 0.23a | 1.18 ± 0.28a |
| 18 August 2021| 7.63 ± 2.87a     | 4.64 ± 1.30b | 3.86 ± 0.76a | 3.57 ± 0.43a |
| 31 August 2021| 4.68 ± 1.78a     | 2.08 ± 0.99b | 2.52 ± 0.30a | 1.12 ± 0.22b |

Net photosynthesis (Pn), water use efficiency (eWUE) of *Vitis vinifera* treated with two different soil management methods: Zeowine (Z) and Compost (C). Different letters within the same parameter indicate significant differences. Data (mean ± S.E., n = 12) were subjected to one-way ANOVA (LSD test, Pn<0.05).
Anthocyanins were recorded for the C treatment at the three different stages. No differences in total polyphenols at harvest were found. At full maturation, no differences in extractable polyphenols were found, while at harvest C berries showed significantly higher extractable polyphenol content compared to the Z treatments.

As for the 2021 season, at mid-, full-maturation and harvest Z berries showed significantly higher extractable and total anthocyanin content compared to C berries. At harvest, Z berries showed significantly higher extractable and total polyphenol content compared to the C treatments.

In both seasons, significant differences were found for the production parameters at harvest (Table 5). Treatment Z, in general, had a higher weight of the bunches and yield per plant compared to the C treatment.

Discussion
To focus on climate change, the main objectives of soil management are to maintain an environment that favours the development of the vegetative apparatus, the accumulation of organic
matter, the absorption of water and the use of nutrients; management that causes drop-in soil skills to reduce these aspects (Smith and Powlison, 2007). However, proper soil management can be expected to restore ecosystem functions that have been degraded (Komatsu-Suzuki and Ohda, 2007).

This study highlights the importance of soil management in the Mediterranean area through the application of a new zeolite-based product against the problems of climate change. Chlorophyll a fluorescence ($F_a/F_{m\text{a}}$, an indicator of photo-oxidative stress; Barolli et al., 2004; Lichtenenthaler et al., 2005) reported differences especially on the hottest days (6–19 August 2019, 3 August 2020 and 18 August 2021). The photo-oxidative shock inhibited photosystem II (PSII) efficiency, as suggested by the reduction of $F_v/F_m$ ratios (Pietrini et al., 2005). We hypothesize, that in the C treatment, the extreme temperature-induced photo-oxidative stress as could be derived from increased expression of reactive oxygen species (ROS) scavengers and an increased pool size of the xanthophyll cycle pigments (Jaghdani et al., 2021). Consequently, in C treatment, a robust inhibitory effect on photosynthetic capacity and net CO$_2$ assimilation (Pn) was reported during that period, as a typical impact of PSII deficiency (Pintó-Marijuan and Mumé-Bosch, 2014). Gaseous exchanges were affected in zeolite-treated vines; Zeowine showed higher rates of photosynthesis vs C treatment (De Smedt et al., 2017). The photosynthesis trend during the seasons of both treatments reflected that temperature directly influenced the photosynthesis rate by stimulating the activity of photosynthetic enzymes and the electron transport chain (ETC) (Slot and Winter, 2017). At low temperatures, the Pn rate increased proportionally with the temperature until it reached an optimum (Long, 1983). The higher-summer temperatures reduced C photosynthesis (i.e. during 2020, on August 3th maximum temperature was 30°C led to the following photosynthesis values: C treatment 3.77 μmol CO$_2$/m$^2$/s and Z treatment 7.30 μmol CO$_2$/m$^2$/s). In addition, an increase in the air temperature for the C treatment indirectly led to increased leaf temperature, which could stimulate water loss by transpiration and elevate vapour pressure deficit (VPD) (Yang et al., 2012). Probably the effect on leaf temperature was mediated by water availability, as it was observed from stem water potential data. As with barley and corn seedlings (Krutulina et al., 2000), the application of zeolite to the vineyard soil was found to increase photosynthetic activity.

In contrast to what was observed by Steiman et al. (2007) the WUE of zeolite treated plants was usually higher to compost vines, suggesting that zeolites did increase water consumption with increasing CO$_2$ fixation (Chaves et al., 2004). Due to zeolitic ability to retain water (Sepaskhah and Barzegar, 2010), plants treated with clinoptilolite (Zeowine) showed significantly lower leaf temperatures in both seasons than zeolite-free composting plants. The following reductions were recorded during 2019: –1.25% on June 21st, –2.14% on July 9th, –8.14% on July 17th, –5.81% on July 22nd, –7.90% on July 31st, –7.11% on August 19th. The following reductions were recorded during 2020: –1.11% on May 22nd, –3.79% on June 9th, –3.49% on June 22nd, –1.58% on July 2nd, –2.77% on July 13rd, –2.85% on August 3rd. Instead, the following reductions were recorded during 2021: –7.00% on June 28th, –2.51% on 5th July, –3.69% on 12 July, –5.17% on 29 July, –1.47% on 18th August and –4.66% on 31st August. Probably the lower transpiration rates of compost-treated plants may explain the higher leaf-air temperature that was observed (De Smedt et al., 2015).

In all seasons the Sanforte cultivar recorded valuable stomatic conductance values, reflecting its anisohydric-conservative behaviour (drought-tolerance) under stress conditions, keeping stomas always open (Rogiers et al., 2012), despite the fall in water potential for compost treatment.

![Fig. 5](https://www.cambridge.org/core/core/terms. https://doi.org/10.1017/S0021859621000915)
In our study the synergy of compost and zeolite positively affected water stress; due to the zeolitic skill of adsorption and release water (Polat et al., 2003), the Zeowine application showed less negative water potential values during the most succyctic period in all years (2019, 2020 and 2021). In fact, several studies on species other than the grapevine also reported that water deficit stress was mitigated by soil applications of zeolite such as in Aloe vera L. (Hazrati et al., 2017), in Trigonella foenum-graecum (Baghbani-Arani et al., 2017), in Oryza sativa L. (Zheng et al., 2018), in Hordeum vulgare L. (Ahmed et al., 2017) and in Cucumis sativus L. (Mohabbati et al., 2018). Zeolite increased the water-holding capacity of the soil and improved soil quality in the root zone (AL-Busaidi et al., 2011).

During the 2020 season, significant differences at full veraison, mid-maturation and harvest were noted in sugar content, while during the 2021 season, significant differences at mid-, full-maturation and harvest were noted in sugar content: Z had the highest values than C treatment. At the time of harvest, Zeowine increased the sugar content of 5.50% in 2020 and 2.00% in 2021. We hypothesize that the higher sugar content of Zeowine-treated plants was due to their higher rate of photosynthesis (Medrano et al., 2003). A close link between photosynthesis (Rubisco activity) and vine carbohydrate metabolism was found and it was observed that the photosynthesis rate (Pn) was directly related to the rate of the sugar metabolic process (Mao et al., 2018). Moreover, we hypothesize that this correlation was due to the young age of the plants; in fact, as there were few stored carbohydrates, berry sugar accumulation was more sensitive to photosynthesis. Vines subjected to zeolite foliar applications (chabasite-rich-zeolite) in addition to significantly reducing grey mould and sour rot infections, increased sugar and alcohol content. In addition, these effects have been linked to the reduction of the leaf temperature, in this case, due to zeolite ability to reflect infrared radiation (Calzarano et al., 2020). However, it cannot be excluded the zeolite capacity to absorb carbon dioxide, determining its increase near the stomata and net photosynthesis increase (De Smedt et al., 2017). This aspect deserves more and deeper investigation.

A 23% (2020) and 31% (2021) increase in the weight of the harvest berry for zeowine treatment was also observed; the ability of zeolite to improve the radical water microclimate led to more hydrated and larger berries (Baesa et al., 2007).

Regarding phenolic maturity, the greatest differences were found in the composition of extractable and total anthocyanins. At full maturation and harvest, Z berries showed significantly higher extractable and total anthocyanin content compared to C berries (2020). The lowest values in total anthocyanins were recorded for the C treatment at the three different stages during the seasons. At mid-, full-maturation and harvest Z berries showed significantly higher extractable and total anthocyanin content compared to C berries (2021). The higher Brix degree of Z treatment may explain the increased accumulation of anthocyanins in the berries (sugar/anthocyanin relationship) (Hernández-Hierro et al., 2014). In fact, it was demonstrated that differences in the anthocyanin extractability were highly influenced by the ripeness degree and also, by the soluble solids contents (Hernández-Hierro et al., 2012). During the 2020 season, no differences in total polyphenols at harvest were found. At full maturation, no differences in extractable polyphenols

### Table 3. Technological maturity

| Survey date | Sugar content ('Brix) | TA (mg/l Tartaric acid) |
|-------------|----------------------|------------------------|
|             | Z                    | C                      | Z                      | C                      |
| 3 August 2020 | 17.00 ± 0.06a         | 16.00 ± 0.09b          | 10.80 ± 0.02a           | 10.40 ± 0.04b          |
| 17 August 2020 | 22.05 ± 1.00a         | 22.80 ± 0.08a          | 8.60 ± 0.03b            | 8.90 ± 0.02a           |
| 3 September 2020 | 22.25 ± 0.04a         | 21.05 ± 0.06b          | 7.12 ± 0.06a            | 7.00 ± 0.06a           |
| 8 September 2020 | 27.25 ± 0.05a         | 25.85 ± 0.03b          | 6.52 ± 0.02b            | 6.65 ± 0.05a           |
| 29 July 2021  | 17.40 ± 0.01a         | 16.80 ± 0.03a          | 12.60 ± 0.02b           | 13.8 ± 0.05a           |
| 18 August 2021 | 20.20 ± 0.04a         | 19.10 ± 0.03b          | 10.20 ± 0.04b           | 11.20 ± 0.03a          |
| 31 August 2021 | 24.80 ± 0.07a         | 23.40 ± 0.05b          | 8.10 ± 0.04b            | 9.20 ± 0.06a           |
| 10 September 2021 | 26.12 ± 0.02a        | 25.68 ± 0.08b          | 7.70 ± 0.02a            | 7.66 ± 0.07a           |

Survey date | pH | Berry weight (g) |
|-------------|----|-----------------|
| 3 August 2020 | 2.95 ± 0.01a | 2.90 ± 0.01a |
| 17 August 2020 | 3.21 ± 0.01a | 3.14 ± 0.01b |
| 3 September 2020 | 3.29 ± 0.02a | 3.29 ± 0.01a |
| 8 September 2020 | 3.41 ± 0.02a | 3.39 ± 0.02b |
| 29 July 2021  | 2.91 ± 0.01a | 2.89 ± 0.01a |
| 18 August 2021 | 3.01 ± 0.01a | 2.99 ± 0.02a |
| 31 August 2021 | 3.12 ± 0.02b | 3.22 ± 0.01a |
| 10 September 2021 | 3.40 ± 0.01a | 3.36 ± 0.01b |

Sugar content ('Brix), titratable acidity (TA), pH and berry weight of Sanforte berries treated with two different soil managements: Zeowine (Z) and Compost (C). Data (mean ± S.E., n = 12) were subjected to one-way ANOVA. Different letters within the same parameter and row indicate significant differences (LSD test, P < 0.05)
were found, while at harvest C berries showed significantly higher extractable polyphenol content compared to the Z application. During the 2021 season, significant differences in polyphenols at harvest were found; Z berries showed significantly higher extractable and total polyphenol content compared to the C application. Increases in total anthocyanins, but also in total polyphenols and colour intensity, were recorded in wine obtained from vines treated with zeolite leaf applications (Calzarano et al., 2019). Again, the leaf temperature reduction effect may have been decisive, for these results, because linked to higher biosynthesis of phenolic compounds (Conde et al., 2016; Movahed et al., 2016). Considering the promising results obtained by zeolite leaf applications, and in this study, by zeolite soil applications, their synergic use may be desirable, with a view to environmentally friendly crop management.

Table 4. Phenolic maturity

| Survey date     | Z             | C             | Z             | C             |
|-----------------|---------------|---------------|---------------|---------------|
| Total anthocyanin (mg/l) |               |               |               |               |
| 3 August 2020   | 505.75 ± 15.06a | 498.75 ± 22.54a | 264.25 ± 12.80a | 262.50 ± 20.10a |
| 17 August 2020  | 848.75 ± 31.45a | 803.25 ± 13.90b | 379.75 ± 24.66a | 350.55 ± 11.74a |
| 3 September 2020| 965.45 ± 17.75a | 810.49 ± 24.31b | 570.61 ± 28.90a | 460.00 ± 24.89b |
| 8 September 2020| 1042.2 ± 22.87a | 844.34 ± 32.78b | 610.45 ± 25.76a | 485.13 ± 27.87b |
| 29 July 2021    | 297.50 ± 21.77a | 269.50 ± 11.57a | 122.50 ± 12.74a | 113.75 ± 10.21a |
| 18 August 2021  | 810.25 ± 33.80a | 586.25 ± 15.90b | 375.00 ± 20.70a | 241.50 ± 18.29b |
| 31 August 2021  | 938.00 ± 25.55a | 745.50 ± 23.56b | 350.00 ± 18.33a | 290.50 ± 16.33b |
| 10 September 2021| 715.05 ± 18.49a | 632.80 ± 31.43b | 312.9 ± 23.78a | 252.00 ± 22.15b |
| Extractable anthocyanin (mg/l) |               |               |               |               |
| 3 August 2020   | 2188.81 ± 40.01a | 2041.55 ± 48.65b | 2046.63 ± 25.65a | 1977.66 ± 27.32a |
| 17 August 2020  | 1725.22 ± 37.80b | 2011.09 ± 33.12a | 1724.20 ± 30.13b | 1864.97 ± 12.54a |
| 3 September 2020| 2025.25 ± 39.45b | 2156.90 ± 35.15a | 1783.87 ± 28.34a | 1708.34 ± 29.04a |
| 8 September 2020| 1940.31 ± 42.57a | 1976.26 ± 39.76a | 1535.61 ± 22.10b | 1613.36 ± 23.05a |
| 29 July 2021    | 2003.47 ± 45.31a | 1894.31 ± 35.50b | 1835.91 ± 37.41a | 1488.10 ± 20.50b |
| 18 August 2021  | 1757.21 ± 35.25a | 1543.95 ± 32.22b | 1455.09 ± 34.21a | 1401.78 ± 24.37a |
| 31 August 2021  | 1635.34 ± 38.32a | 1450.01 ± 37.41b | 1137.4 ± 28.36b | 1312.92 ± 28.25a |
| 10 September 2021| 1540.90 ± 40.75a | 1338.81 ± 39.55b | 1434.27 ± 27.72a | 1183.95 ± 28.50b |

Total anthocyanin (Tot. Anth.), extractable anthocyanin (Extr. Anth.), total polyphenol (Tot. Polyp.) and extractable polyphenol (Extr. Polyp.) content of Sanforte berries treated with two different soil managements: Zeowine (Z) and Compost. Data (mean ± S.E., n = 12) were subjected to one-way ANOVA. Different letters within the same parameter and row indicate significant differences (LSD test, P ⩽ 0.05).

Table 5. Production parameters

| Survey date     | N° cluster/vine | Cluster weight (kg) | Yield/vine (kg) |
|-----------------|-----------------|---------------------|-----------------|
|                 | Z               | C                   | Z               | C               |
|                 | Z               | C                   | Z               | C               |
| 8/9/2020        | 5.26 ± 0.06a    | 4.80 ± 0.04b        | 0.19 ± 0.06a    | 0.15 ± 0.08b    | 0.98 ± 0.03a    | 0.88 ± 0.04b     |
| 10/9/2021       | 6.00 ± 0.03a    | 6.60 ± 0.07a        | 0.21 ± 0.07a    | 0.18 ± 0.07b    | 1.25 ± 0.05a    | 0.88 ± 0.03b     |

Cluster weight (kg), yield/vine (kg) and a number of cluster/vine of Sanforte cv. With two different soil management: zeowine (Z) and compost. Different letters within the same parameter indicate significant differences. Data (mean ± S.E., n = 12) were subjected to one-way ANOVA (LSD test, P ⩽ 0.05).

Based on the findings of this experiment, it could be concluded that the deleterious effects of global warming, in a new grapevine plant, can be reduced with Zeowine soil improver. The zeolite skill to hold water and exchange nutrients, gave the vines the strength to improve their performance and carry out better production than the compost treatment. The features of zeolite combined with compost could be one of the best solutions to make a stand against drought problems. Therefore, it is in this scenario that the application of Zeowine in the vineyard to the soil can be a valid tool to mitigate the effects of climate change.
However, further investigations are needed, given the few studies carried out on the application of zeolites in vineyards.

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