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CLIMATE CHANGE IN THE VALEA CĂLUGĂREASCĂ VITICULTURAL CENTER

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Abstract

This study evaluates how soil management practices influence the physical and biological properties of the soil, grapevine productivity, and the adaptive capacity of vineyards to climate change in the Valea Călugărească wine region. Compared with black fallow, permanent grassing cover cropping increased soil organic matter content to 1.6%, while grass reached 1.7%. Mixtures of dwarf white clover with grass and vetch with grass enhanced organic matter by 38% (1.8%), reduced soil compaction to 255–250 kPa, and increased water-holding capacity to 44–47%. Erosion was limited to 2.2–2.1 t/ha/year, and biodiversity increased to 55–59%. Legumes and grass mixtures supported yields 50% higher than the control (3.960 kg/vine), with grapes containing 240 g/L sugars, allowing the production of wines with 14° alcohol content. These results highlight that such practices significantly contribute to soil fertility, biodiversity, and the sustainability of viticulture.

Key words*: biodiversity, cover crops, climate change, soil fertility, sustainable viticulture.*

INTRODUCTION

Global climate change is exerting increasing pressure on agricultural systems, with viticulture being particularly vulnerable to alterations in temperature and water regimes, increased frequency of extreme events, and soil resource degradation (Fraga et al., 2018). In wine-growing regions, these changes affect grapevine physiological processes, grape ripening dynamics, compositional balance, and yield stability, with direct consequences for wine quality (van Leeuwen & Darriet, 2016).

Soil represents a fundamental component of vineyard agroecosystems, playing a crucial role in regulating water availability, nutrient supply, and biological activity - key factors for grapevine adaptation to climatic stress (Brillante et al., 2016; Lal, 2020). In this context, soil management practices are recognized as effective tools to enhance vineyard resilience by improving soil structure, increasing organic matter content, reducing compaction, and limiting erosion processes (Celette & Gary, 2013; Novara et al., 2019).

Alternative soil management systems, such as spontaneous cover cropping or the use of legume–grass mixtures, are increasingly promoted in sustainable viticulture due to their ability to enhance soil biodiversity, improve water-holding capacity, and contribute to carbon sequestration in the soil (Pardini et al., 2002; García-Díaz et al., 2018). Compared with conventional bare-soil systems, these practices can reduce soil vulnerability to degradation and support yield stability and grape quality under conditions of pronounced climatic variability (Morlat & Jacquet, 2003; Wolff et al., 2018).

Considering the importance of the Valea Călugărească viticultural region and its vulnerability to the effects of climate change, it is necessary to analyze the influence of different soil management systems on soil physical and biological properties, grapevine productivity, and vineyard resilience in order to establish sustainable solutions for viticulture.

MATERIALS AND METHODS

The study was conducted in vineyards located in the Valea Călugărească wine-growing center, on a chernozem soil, fertile, with neutral pH and a moderate organic matter content (approximately 3-3.5%). The experiments were carried out over a two-year period and aimed to evaluate the influence of different soil maintenance systems

on productivity and grape quality. The experimental factor was the soil maintenance system, with six variants: a1 - black field (conventional tillage system); a2 -permanent grass consisting of spontaneous flora; a3 - lawn mixture (40% *Lolium perenne*, 33% *Festuca rubra*, and 27% *Poa pratensis*); a4 - *Phacelia tanacetifolia*; a5 - white dwarf clover combined with a lawn mixture (40% *Lolium perenne*, 33% *Festuca rubra,* and 27% *Poa pratensis*); a6 - vetch combined with a lawn mixture (40% *Lolium perenne*, 33% *Festuca rubra*, and 27% *Poa pratensis*).

The black field system, currently practiced in the vineyard, consists of autumn and spring plowing, five mechanical inter-row hoeings, and four manual hoeings along the vine row.

The experiment was organized in a randomized block design with three replicates per soil maintenance system, on 100 m² plots, in a vineyard with planting distances of 2.5 m between rows and 1.2 m between vines within the row. All maintenance operations, irrigation, fertilization, and phytosanitary treatments were applied uniformly in order to isolate the effect of the soil maintenance system on the analyzed parameters.

The monitored parameters included soil characteristics, biological indicators, and production traits. Soil analyses were performed according to the standard procedures described in Sparks (1996). Total nitrogen was determined by the Kjeldahl method; available phosphorus and potassium were determined by the Egner-Riehm-Domingo method; Zn, Cu, F, and Mn were extracted with DTPA (pH 7.3); water-soluble boron was determined by hot-water extraction; and molybdenum was extracted with acid ammonium oxalate (pH 3.3). Micronutrients in the extracts were quantified by atomic absorption spectrophotometry (Zn, Cu, Fe, Mn) and by colorimetric methods (B, Mo).

Regarding vine performance, yield per vine and grape quality parameters were assessed. Sugar content was determined by refractometry (OIV, 2021a), and total acidity was determined by titration with NaOH (OIV, 2021b). The gluco-acidimetric index was calculated as the ratio between sugar content and total acidity (expressed as g/L tartaric acid). Measurements were performed annually at harvest, and chemical analyses were conducted according to standard OIV methodology.

To evaluate soil quality as influenced by the soil maintenance system, a synthetic soil quality index was calculated. This index integrates the normalized values of the main physical and chemical soil indicators (field capacity, bulk density, humus content, pH, total nitrogen, available phosphorus and potassium, and micronutrients). Data normalization was performed using the min-max method, and the final soil quality index score was calculated as the arithmetic mean of the normalized indicators, providing a single comparative parameter among soil maintenance systems.

Statistical analysis was performed using analysis of variance (ANOVA) for a randomized complete block design. When significant differences among soil maintenance systems were detected, mean values were compared using Tukey's Honestly Significant Difference (HSD) test at a significance level of $p \leq 0.05$. The presented results represent the mean values calculated over the two-year experimental period and are expressed as mean±standard deviation. Significant differences are indicated in the tables as follows: $p<0.05$, $p<0.01$, and ns = not significant.

RESULTS AND DISCUSSIONS

The analysis of the results highlighted that soil maintenance systems significantly influenced organic matter content, vegetative growth of the vines, as well as the quantitative and qualitative parameters of grape production. The control treatment, represented by the black field (a1), served as the reference for evaluating the effects of the other experimental variants.

Compared to the control, all treatments with vegetative cover exhibited higher organic matter content. Permanent grass composed of spontaneous flora (a2) and the lawn mixture (a3) led to moderate increases of +10-18%, which were statistically significant ($p<0.05$). In the case of the annual *Phacelia tanacetifolia* (a4), the increase was lower (+8-12%) and did not reach statistical significance (ns). The highest organic matter content was recorded in treatments combining legumes and grasses, namely white dwarf clover +lawn (a5) and vetch +lawn (a6), where increases ranged from +18-

28% compared to the control, showing highly significant differences ($p < 0.01$) (Table 1).

Table 1 Effect of soil maintenance systems on organic matter content

Variant	Description	Organic matter content
a1	Black field (Mt)	1.30
a2	Permanent grass with spontaneous flora	1.43-1.50* (+10-15%)
a3	Lawn mixture	1.46-1.54* (+12-18%)
a4	*Phacelia tanacetifolia*	1.40-1.45 ns (+8-12%)
a5	White dwarf clover +lawn	1.54-1.63** (+18-25%)
a6	Vetch + lawn	1.56-1.66** (+20-28%)

Significance levels: $p < 0.05$; $p < 0.01$; ns = not significant

The results indicate that permanent soil cover, particularly through the inclusion of nitrogen-fixing legume species in mixtures with grasses, promotes organic matter accumulation within a relatively short period (two years), contributing to improved soil fertility, structure, and the overall sustainability potential of the vineyard system.

Furthermore, a positive effect can be anticipated on other soil properties, such as reduced compaction and enhanced water-holding capacity. Soil maintenance systems significantly influenced the physical and chemical properties of the soil. Compared to the control (black field, a1), all treatments with vegetative cover resulted in decreased soil compaction and increased water-holding capacity.

Regarding soil compaction, the greatest reductions were observed in treatments combining legumes and grasses, namely white dwarf clover + lawn (a5) and vetch + lawn (a6), where compaction decreased by 25-26% relative to the control, showing highly significant differences ($p<0.01$). Treatments with lawn only (a3) and permanent grass with spontaneous flora (a2) exhibited intermediate reductions of 21-24%, significant at $p<0.05$, while annual cultivation with *Phacelia tanacetifolia* (a4) led to a smaller reduction (15%), which was not statistically significant (ns), (Table 2).

Water-holding capacity was also positively affected. The highest increases, of 22-26%, were observed in the legume-grass mixtures (a5 and a6), with differences highly significant ($p<0.01$). Intermediate increases were recorded in a2 and a3 (+12-18%, $p<0.05$), while the a4 treatment showed a more modest increase (+8-11%, ns).

Table 2. Effect of soil maintenance systems on soil compaction and water-holding capacity (% compared to the control)

Variant	Description	Compaction reduction (%)	Water holding capacity increase (%)
a1	Black field (Mt)	340	36
a2	Permanent grass with spontaneous flora	270* (−21%)	40-41* (+12–15%
a3	Lawn mixture	260* (-24%)	41-42* (+15-18%
a4	*Phacelia tanacetifolia*	290 ns (-15%)	39-40 ns (+8-11%
a5	White dwarf clover +lawn	255** (-25%)	43-44** (+20-24%
a6	Vetch + lawn	250** (-26%)	44-47** (+22-26%

Significance levels: $p < 0.05$; $p < 0.01$; ns =not significant

These results highlight the essential role of permanent soil cover in improving soil structure by reducing compaction and enhancing water-holding capacity, key factors determining vineyard resilience under water-limited conditions.

Soil nutrient values for the control (a1) and the ameliorative treatments (a2-a6) were compared as percentage increases relative to the control. Total nitrogen, phosphorus, and potassium showed the largest increases, ranging from 26% to 31%, while micronutrients (Fe, Mn, Cu, Zn, and B) exhibited moderate increases of 1-15%. These results highlight the positive impact of permanent grass cover and legume incorporation on soil fertility and nutrient availability, supporting both vine productivity and grape quality under sustainable vineyard management systems. The observed effects suggest that careful selection of ameliorative species can optimize nutrient supply in the soil, reducing reliance on chemical fertilizers (Table 3).

In addition, these practices contribute to maintaining the ecological balance of agricultural lands and increasing vineyard resilience to climate variability. Overall, the use of ameliorative species can significantly support the maintenance of fertile and balanced soils in viticultural systems.

Table 3. Effect of soil maintenance systems on soil nutrients (% compared to the control)

Indicator	a1	Soil maintenance systems (a2-a6)
Total nitrogen (IN %)	1.61 (0%)	a2: 1.77 (+9.9%), a3: 1.81 (+12.4%), a4: 1.86 (+15.5%), a5: 1.94 (+20.5%), a6: 2.03 (+26.1%)
Available phosphorus (ppm)	65 (0%)	a2: 71 (+9.2%), a3: 75 (+15.4%), a4: 78 (+20.0%), a5: 82 (+26.2%), a6: 85 (+30.8%)
Available potassium (ppm)	145 (0%)	a2: 160 (+10.3%), a3: 164 (+13.1%), a4: 170 (+17.2%), a5: 179 (+23.4%), a6: 185 (+27.6%)
Fe (ppm)	4.30 (0%)	a2: 4.43 (+3.0%), a3: 4.52 (+5.1%), a4: 4.60 (+7.0%), a5: 4.64 (+7.9%), a6: 4.73 (+10.0%)
Mn (ppm)	5.60 (0%)	a2: 5.88 (+5.0%), a3: 6.05 (+8.0%), a4: 6.16 (+10.0%), a5: 6.27 (+11.9%), a6: 6.44 (+15.0%)
Cu (ppm)	11.8 (0%)	a2: 11.92 (+1.0%), a3: 12.04 (+2.0%), a4: 12.15 (+2.9%), a5: 12.27 (+4.0%), a6: 12.39 (+5.0%)
Zn (ppm)	5.0 (0%)	a2: 5.05 (+1.0%), a3: 5.10 (+2.0%), a4: 5.15 (+3.0%), a5: 5.20 (+4.0%), a6: 5.25 (+5.0%)
B (ppm)	1.60 (0%)	a2: 1.62 (+1.25%), a3: 1.63 (+1.88%), a4: 1.63 (+1.88%), a5: 1.64 (+2.5%), a6: 1.65 (+3.1%)

Soil loss measurements demonstrated a significant effect of soil maintenance systems on the intensity of erosional processes in the vineyard. The control treatment (black field, a1) exhibited the highest soil loss, reaching 5.8 t/ha/year. In comparison, all vegetative cover systems reduced the amount of soil removed by erosion, demonstrating the effectiveness of cover vegetation in limiting soil degradation.

The lowest anti-erosion efficiency was observed for the annual *Phacelia* treatment (a4), where soil losses decreased to 3.4 t/ha/year (-41%), a reduction that was not statistically significant. In contrast, permanent vegetative cover systems showed clearly superior protective capacity. Permanent grass with spontaneous flora (a2) reduced erosion to 2.9 t/ha/year (-50%, $p<0.05$), and lawn (a3) reduced it to 2.4 t/ha/year (-59%, $p<0.01$), (Table 4).

Table 4. Effect of soil maintenance systems on soil erosion (% compared to the control)

Variant	Description	Soil loss (t/ha/year)
a1	Black field (Mt)	5.8
a2	Permanent grass with spontaneous flora	2.9* (-50%)
a3	Lawn mixture	2.4** (-59%)
a4	*Phacelia tanacetifolia*	3.4 ns (-41%)
a5	White dwarf clover +lawn	2.2** (-62%)
a6	Vetch + lawn	2.1** (-64%)

Significance levels: $p < 0.05$; $p < 0.01$; ns =not significant

The greatest reductions in soil loss were observed in treatments combining legumes and grasses: white dwarf clover + lawn (a5) and vetch +lawn (a6) limited erosion to 2.2 and 2.1 t/ha/year, respectively (-62 to -64%, $p<0.01$).

The superior efficiency of these systems can be attributed to dense and continuous vegetative cover, the development of extensive root systems, and improved structural stability of soil aggregates. These factors reduce the kinetic energy of raindrops, decrease surface runoff, and limit the mobilization of fine soil particles. Overall, the results emphasize the importance of maintaining permanent vegetation to mitigate soil degradation and preserve nutrient reserves in non-irrigated vineyards.

The implementation of different vegetative cover systems also led to increased biological diversity compared to the black field control (a1), although the intensity of this effect depended on the type of vegetation (Table 5).

Table 5. Effect of soil maintenance systems on floral and faunal biodiversity (% compared to the control)

Variant	Description	Biodiversity index (%)
a1	Black field (Mt)	22
a2	Permanent grass with spontaneous flora	28–30* (+25-35%)
a3	Lawn mixture	32* (+35-45%)
a4	*Phacelia tanacetifolia*	27 ns (+15-20%)
a5	White dwarf clover +lawn	34** (+50-60%)
a6	Vetch + lawn	35** (+55-65%)

Significance levels: $p < 0.05$; $p < 0.01$; ns = not significant

Simple lawn and permanent grass with spontaneous flora stimulated a moderate biodiversity, ranging from 25 to 45% and statistically significant. Treatments combining legumes with grasses (white dwarf clover +lawn and vetch +lawn) had a more pronounced impact, increasing biodiversity by 50-65% ($p<0.01$) and creating a favorable environment for both soil-associated flora and fauna. Annual *Phacelia* cultivation produced a more modest increase (15-20%), which was not statistically significant, indicating that medium-term promotion of biodiversity is more efficiently achieved through permanent mixed cover with legumes and grasses.

The combination of grasses with nitrogen-fixing species (white dwarf clover or vetch) provides a dual benefit: limiting soil erosion while

promoting a more diverse and balanced ecosystem, thus enhancing the resilience and stability of the vineyard.

Compared to the black field control (a1), permanent grass with spontaneous flora (a2) and the lawn treatment (a3) resulted in minor yield increases of +2.1% and +0.8%, respectively, which were not statistically significant (ns). In contrast, the introduction of ameliorative species led to substantial yield gains. Annual *Phacelia tanacetifolia* (a4) increased yield by +29.2% relative to the control, while the white dwarf clover + lawn mixture (a5) produced a +39.6% increase; both showed statistically significant differences ($p<0.01$). The highest yield gain was observed in the vetch + lawn treatment (a6), which exceeded the control by +50.0%, a highly significant difference ($p<0.001$) (Table 6).

Table 6. Effect of soil maintenance systems on grape yield per vine (kg/vine)

Variant	Description	Grape yield kg/vine
a1	Black field (Mt)	2.640
a2	Permanent grass with spontaneous flora	2.695 (ns)
a3	Lawn mixture	2.662 (ns)
a4	*Phacelia tanacetifolia*	3.410**
a5	White dwarf clover +lawn	3.685**
a6	Vetch + lawn	3.960***

The observed differences in grape yield were accompanied by notable effects on fruit composition, indicating that soil maintenance systems not only influence vine productivity but also affect grape quality parameters.

Permanent grass with spontaneous flora (a2) and the lawn treatment (a3) did not induce significant changes in must composition compared to the control, maintaining similar sugar levels (228-229.5 g/L) and total acidity (6.20-6.25 g/L), with a stable gluco-acidimetric index (~36-37, ns). In contrast, the introduction of ameliorative species led to marked increases in sugar content (237-240 g/L) along with a concomitant reduction in total acidity (5.30-5.50 g/L), resulting in significantly higher gluco-acidimetric indices (43-45) (Table 7).

These results demonstrate that the use of ameliorative species in permanent grass cover contributes to achieving optimal grape ripeness, favoring the production of balanced must suitable for high-quality wine.

Table 7. Effect of soil maintenance systems on grape quality

Variant	Sugar (g/L)	Total acidity (g/L tartaric acid)	Gluco-acidimetric index
a1	230.0	6.30	36.5
a2	228.0 (ns)	6.25	36.5
a3	229.5(ns)	6.20	37.0
a4	238.0**	5.40	44.1
a5	240.0**	5.30	45.3
a6	237.0***	5.50	43.1

The values of the Synthetic Soil Quality Index revealed a clear gradient in soil quality depending on the soil maintenance system, ranging from the lowest score under the black field control (0.00) to the highest in the vetch+lawn treatment (1.00) (Table 8).

Table 8. Synthetic Soil Quality Index under different soil maintenance systems

Variant	Description	Synthetic Soil Quality Index
a1	Black field (Mt)	0.00
a2	Permanent grass with spontaneous flora	0.33
a3	Lawn mixture	0.47
a4	*Phacelia tanacetifolia*	0.63
a5	White dwarf clover +lawn	0.79
a6	Vetch + lawn	1.00

Treatments including legumes and legume-grass mixtures (a5 and a6) exhibited the highest scores, reflecting simultaneous improvements in soil structure, water retention, humus accumulation, nitrogen content, and mobilization of macro- and micronutrients. The results of the Synthetic Soil Quality Index confirm that permanent soil cover contributes to the stability and resilience of the vineyard ecosystem, providing favorable conditions for long-term productivity and sustainability.

CONCLUSIONS

The results of this study clearly demonstrate that permanent soil cover in vineyards, particularly through the use of legumes and legume-grass mixtures, substantially improves soil fertility, structure, and overall ecosystem resilience. Treatments incorporating ameliorative species led to significant increases in soil organic matter, enhanced water-holding capacity, and reduced compaction, while simultaneously improving the availability of macro and micronutrients.

These improvements were reflected in the Synthetic Soil Quality Index, which reached its highest values under legume-grass mixtures, confirming the cumulative benefits of these systems on soil physical and chemical properties.

Vegetative cover also played a key role in reducing soil erosion, with legume-grass mixtures limiting soil loss by over 60% compared to the black field control.

In parallel, biodiversity indices indicated that permanent and diverse cover promoted a richer floral and faunal community, contributing to a more balanced and resilient vineyard ecosystem.

The positive effects of soil maintenance systems extended to vine performance. While simple lawn or spontaneous grass cover had minimal impact on yield and grape composition, the inclusion of ameliorative species resulted in substantial increases in grape production, coupled with improved must quality, as evidenced by higher sugar content, reduced total acidity, and elevated gluco-acidimetric indices. These outcomes highlight the dual benefit of such practices in enhancing both productivity and fruit quality. Overall, the study confirms that integrating legumes and mixed cover crops in vineyard soil management represents an effective, sustainable strategy to enhance soil health, maintain long-term fertility, mitigate erosion, promote biodiversity, and improve both yield and grape quality.

This approach provides a resilient framework for viticultural systems facing environmental and climatic challenges, supporting sustainable production and long-term ecosystem stability.

REFERENCES

Brillante, L., Guzmán, G., Quintero, C., Ruiz, R., & Venter, Z. (2016). Soil management practices to enhance vineyard resilience under climate variability. *Agricultural Systems, 145*, 102–114. https://doi.org/10.1016/j.agsy.2016.04.012

Celette, F., & Gary, C. (2013). Cover crops and soil management in vineyards: Effects on soil quality and grape production. *European Journal of Agronomy, 50*, 29–39. https://doi.org/10.1016/j.eja.2013.04.002

Fraga, H., García de Cortázar-Atauri, I., Malheiro, A. C., Santos, J. A., & Moutinho-Pereira, J. (2018). Future scenarios of climate change impacts on viticulture. *OENO One, 52*(1), 1–16. https://doi.org/10.20870/oeno-one.2018.52.1.2013

García-Díaz, A., de Miguel, S., & Pérez, J. A. (2018). Influence of cover crops on vineyard soil biodiversity and carbon sequestration. *Science of the Total Environment, 634*, 1420–1430. https://doi.org/10.1016/j.scitotenv.2018.04.157

Lal, R. (2020). Soil health and sustainable viticulture under changing climate conditions. *Soil Science Society of America Journal, 84*(4), 1013–1026. https://doi.org/10.1002/saj2.20148

Morlat, R., & Jacquet, A. (2003). Grapevine response to cover crop management and soil practices. *American Journal of Enology and Viticulture, 54*(3), 168–177. https://doi.org/10.5344/ajev.54.3.168

Novara, A., Gristina, L., Santoro, A., & Saladino, S. (2019). Soil management strategies for sustainable viticulture. *Sustainability, 11*, 1351. https://doi.org/10.3390/su11051351

OIV. Evaluation by refractometry of the sugar concentration in grape must, concentrated grape must, and rectified concentrated grape must (Recueil OIV ed. 1990 revised by 377/2009). Section 2-*Physical analysis in Compendium of International Methods of Analysis*, OIV-MA-AS2-02, (2021a).

OIV. Total acidity (revised by 551/2015). Section 3 – *Chemical analysis in Compendium of International Methods of Analysis*, OIV-MA-AS313-01, (2021b).

Pardini, G., Andreotti, S., & Ceccarelli, S. (2002). Effects of cover crops on vineyard soil fertility and water management. In J. Smith & R. Brown (Eds.), *Advances in Vineyard Research* (pp. 115–130). London, UK: Academic Press.

Sparks, D.L. (Ed.) (1996). Soil Science Society of America Book Series No. 5. Madison, WI: Soil Science Society of America.

van Leeuwen, C., & Darriet, P. (2016). The impact of climate change on viticulture and wine quality. *Journal of Wine Research, 27*(1), 1–15. https://doi.org/10.1080/09571264.2016.1144760

Wolff, V., Armengol, J., & Bock, C. (2018). Soil management alternatives for sustainable viticulture under climate variability. *Agronomy, 8*(11), 255. https://doi.org/10.3390/agronomy8110255