

Effects of Bacterial and Organic Fertilizer Sources on Yield, Fruit Quality and Leaf Nutrient Status of Boğazkere Grapevine (*Vitis vinifera* L.) under Calcareous Semi-Arid Conditions

Berfin Kızgın

Dicle University

Gültekin Özdemir

gozdemir@dicle.edu.tr

Dicle University

Research Article

Keywords: Bacterial biofertilizer, PGPR, Calcareous soil, Total soluble solids, Vermicompost, *Vitis vinifera* L

Posted Date: August 13th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10471115/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

Abstract

Organic viticulture in semi-arid regions depends on organic fertilizer sources, but their effectiveness on calcareous, phosphorus-deficient soils needs further field quantification. Six organic fertilizer sources (bacterial biofertilizer, bat manure, farmyard manure, compost and vermicompost in solid and liquid forms, and a commercial organic fertilizer applied to soil or foliage), each at three rates, together with an untreated control, were compared on seven-year-old own-rooted 'Boğazkere' vines grown in a slightly alkaline (pH 7.6–7.7), calcareous (13.0–16.7% CaCO₃) vineyard soil in Diyarbakır, Türkiye, during the 2021 growing season. The 28 treatments were arranged in a randomized complete block design with three replicates of three vines each. Yield, cluster and berry traits showed no significant differences among treatments ($p > 0.05$); vine yield ranged from 7.07 to 15.22 kg vine⁻¹, the highest under the bacterial biofertilizer at 100 mL. Must total soluble solids was the only must trait that differed among treatments, increasing from 18.10% in the control to 19.43% under the bacterial biofertilizer at 100 mL (+ 7.3%), while foliar commercial fertilizer at 10 g and liquid compost at 75 mL gave the lowest values (16.87% and 16.63%). Leaf nitrogen remained within the sufficiency range, whereas leaf zinc stayed below the sufficiency threshold in every treatment, including the control. The bacterial biofertilizer at 100 mL vine⁻¹ was the treatment most consistently associated with improved must soluble solids, whereas organic matter-based amendments had no detectable effect on yield or berry composition; the site-wide zinc deficit calls for a separate foliar Zn programme.

Introduction

Grapevine is among the most widely cultivated fruit crops worldwide, and Türkiye ranks among the leading producers both in vineyard area and in the number of cultivars maintained in cultivation, particularly across the Anatolian peninsula, where *Vitis vinifera* has a long documented continuity and a rich heritage of local cultivars (Candar et al. 2021). Production is increasingly concentrated in semi-arid inland regions where summer rainfall is negligible and soils are calcareous and low in organic matter. Under such conditions the nutrients that most often limit vine performance are phosphorus and zinc, both of which form sparingly soluble compounds at high soil pH and in the presence of free calcium carbonate (Marschner 2012; Naseer and Muhammad 2014). Growers in these regions therefore face a nutritional constraint that cannot be resolved simply by raising fertilizer rates, and they must also select cultivars whose climatic envelope matches the local heliothermic and hydrothermic indices, an issue that has been quantified only for a handful of Turkish wine grapes including 'Boğazkere' (Ateş and Uysal 2017).

Organic viticulture adds a further restriction: soluble mineral fertilizers are excluded, and nutrient supply must come from organic sources within systems certified under regulations such as EC 834/2007 and Demeter, which impose upper limits on total nitrogen input and indirectly constrain the pool of mineral nitrogen available to the vine (Döring et al. 2015, 2019). Farmyard manure, compost and vermicompost supply nutrients through mineralization and, at the same time, raise soil organic carbon, lower rhizosphere pH through the release of organic acids, and stimulate microbial activity; each of these

processes can increase phosphorus availability in alkaline soils (Jamal et al. 2023). In vineyards specifically, compost application has been shown to modify soil physical properties and root development and to alter vine performance (Badalíková et al. 2022; Gaiotti et al. 2017), while organic mulches have improved grape composition on nutrient-poor soils (Mairata et al. 2024). A meta-analysis covering a wide range of species reported a mean growth increase of about 13% from vermicompost, although the response varied strongly with dose and substrate (Blouin et al. 2019); in a recent pot study on grapevine, compost and vermicompost derived from the same feedstock nevertheless acted differently, with vermicompost raising CO₂ assimilation and shoot elongation whereas compost increased water-use efficiency and root biomass (Maia et al. 2026).

Microbial biofertilizers form a separate category that acts by improving nutrient acquisition rather than by supplying nutrients in bulk, so that their contribution is largest precisely where phosphorus and zinc are least available. Consortia of nitrogen-fixing and phosphate-solubilizing bacteria release organic acids that lower rhizosphere pH and dissolve calcium-bound phosphate, a mechanism of particular relevance in calcareous soils (Alori et al. 2017; Karaca and Sabir 2017). Such bacteria have alleviated alkaline stress in grapevine rootstocks (Karaca and Sabir 2017) and, applied as a liquid biofertilizer, have promoted *V. vinifera* growth by raising soil enzyme activity and microbial diversity (Lu et al. 2020). Arbuscular mycorrhizal fungi, a second class of microbial inoculant, extend the absorbing surface of the root and have raised vine yield, phosphorus uptake and photosynthetic rate in semi-arid vineyards (Aguilera et al. 2022; Nicolás et al. 2014; Peng et al. 2025). It remains an open question whether such inoculation can produce a measurable effect on the fruit of mature vines within a single season, and documented outcomes are context-dependent: in a recent vineyard trial a commercial inoculant actually reduced °Brix and pH in newly planted vines (Baraza et al. 2024).

'Boğazkere' is a late-ripening, thick-skinned and highly tannic red wine cultivar indigenous to the Diyarbakır region of southeastern Türkiye and carries a protected geographical indication; it has been reported to produce its best quality on calcareous, gravelly, red-coloured soils (Candar et al. 2021). Published work on the cultivar has concentrated almost entirely on phenolic composition and wine chemistry, and its agronomic response to fertilization has not been reported. The present study was designed to fill this gap by comparing six organic fertilizer sources, applied in two physical forms and at three rates, on mature 'Boğazkere' vines growing in a calcareous semi-arid vineyard. We hypothesised that (H1) microbial inoculation would improve nutrient acquisition and berry composition within a single season, whereas (H2) organic matter-based amendments would remain without measurable effect because their mineralisation is delayed by the absence of summer rainfall.

Materials and Methods

Study site and plant material

The experiment was conducted during the 2021 growing season in a commercial vineyard at Döğer, Dicle district, Diyarbakır province, southeastern Türkiye (38°22'27" N, 40°14'33" E; 970 m a.s.l.). The region has

a continental semi-arid climate with hot, effectively rainless summers and cold winters; long-term annual precipitation is 496 mm and falls almost entirely in winter and spring (Turkish State Meteorological Service, 1991–2020 normal). Seven-year-old own-rooted *Vitis vinifera* L. cv. Boğazkere vines grafted on their own roots were used. Vines were spaced 2 m within rows and 3 m between rows, corresponding to a density of approximately 1667 vines ha⁻¹, trained to a wire trellis system and irrigated by drip. The vineyard had been managed organically since establishment, in accordance with Regulation EC 834/2007 and Demeter standards (Döring et al. 2015, 2019). A total of 252 vines, comprising the 27 fertilised treatments plus an untreated control arranged in three replicates of three vines each, were included in the trial. Phenological stages were recorded following OIV descriptors: budburst 23 April, full bloom 20 May, véraison 16 July and maturity 13 September 2021.

Soil analysis

Before the experiment, soil samples were taken from 0–30, 30–60 and 60–90 cm depths and analysed by standard methods for texture, pH, electrical conductivity, CaCO₃, organic matter, total N, available P and K, extractable Ca and Mg, and available Fe, Mn, Zn and Cu. The soil was slightly alkaline throughout the profile (pH 7.6–7.7), non-saline, calcareous to strongly calcareous at the surface, and loam to clay loam in texture. Organic matter ranged from 1.64 to 2.03%, available P was low at all three depths (26.5–49.0 kg P₂O₅ ha⁻¹) and available Zn was likewise low (0.29–0.47 mg kg⁻¹), whereas exchangeable K and Ca were high (Table 1).

Table 1
Physical and chemical properties of the experimental vineyard soil at three depths.

Property	Unit	0–30 cm	30–60 cm	60–90 cm	Rating
pH	–	7.7	7.6	7.6	Slightly alkaline
CaCO ₃	%	16.7	13.0	14.3	Strongly calcareous / Calcareous / Calcareous
Salinity	%	0.026	0.023	0.024	Non-saline
Saturation	%	64	59	59	–
Organic Matter	%	2.03	1.64	1.69	Medium / Low / Low
Total N	%	0.097	0.094	0.096	Sufficient
Available P	kg P ₂ O ₅ ha ⁻¹	44.9	26.5	49.0	Low
Available K	kg K ₂ O ha ⁻¹	1030	1040	1138	High
Extractable Ca	kg CaO ha ⁻¹	20878	23069	23279	High
Extractable Mg	kg MgO ha ⁻¹	896	1180	1145	Sufficient
Available Fe	mg kg ⁻¹	7.34	5.56	5.08	Sufficient
Available Mn	mg kg ⁻¹	3.60	4.88	4.07	Sufficient / High / High
Available Zn	mg kg ⁻¹	0.47	0.32	0.29	Low

Soil texture was loam at 0–30 and 30–60 cm, and clay loam at 60–90 cm.

Treatments and experimental design

Twenty-eight treatments were established: a commercial bacterial biofertilizer at 50, 100 and 150 mL vine⁻¹; bat manure at 400, 500 and 600 mL vine⁻¹; farmyard manure at 0.6, 1.2 and 1.8 kg vine⁻¹; compost applied to soil in solid form at 0.5, 1.0 and 1.5 kg vine⁻¹ and in liquid form at 25, 50 and 75 mL vine⁻¹; vermicompost applied to soil in solid form at 1.5, 2.0 and 2.5 kg vine⁻¹ and in liquid form at 25, 50 and 75 mL vine⁻¹; a commercial organic fertilizer applied to soil at 50, 100 and 150 g vine⁻¹ and to foliage at 10, 15 and 20 g vine⁻¹; and an untreated control. The declared properties of the materials are given in Table 2. The bacterial biofertilizer was a liquid formulation (pH 6–8) containing 5×10^8 live cells mL⁻¹ of a bacterial consortium, namely *Azospirillum brasilense*, *Azotobacter vinelandii*, *A. chroococcum*, *Rhizobium trifolii*, *Pseudomonas fluorescens*, *Bacillus subtilis*, *B. licheniformis*, *B. amyloliquefaciens* and *B. mucilaginosus*. Solid materials were incorporated into basins opened in the root zone; liquid formulations

were applied to the same zone, with the exception of the foliar commercial fertilizer and the foliar-applied liquid compost and vermicompost, which were dissolved in 2 L of water and sprayed onto the canopy with a hand sprayer in the early morning. Farmyard manure, solid compost and solid vermicompost were applied once during dormancy (27 February 2021); the bacterial biofertilizer, bat manure, the liquid formulations and the commercial fertilizer were applied three times, before flowering (20 May), at véraison (16 July), and before the onset of sugar accumulation (21 August 2021). Every soil application was followed by drip irrigation. Treatments were arranged in a randomized complete block design with three replicates, each replicate consisting of three vines.

Table 2
Declared properties of the organic materials used in the experiment.

Material	Form	pH	OM (%)	N (%)	P ₂ O ₅ (%)	K ₂ O (%)
Bacterial biofertilizer	Liquid	6–8	–	–	–	–
Bat manure	Liquid	5.7	31.09	2.5	1.52	6.89
Farmyard manure	Solid	7.8	47.0	1.71	0.25	1.10
Compost, solid	Solid	4.7	58.82	–	–	–
Compost, liquid	Liquid	3.6–5.6	30.0	2.0	–	–
Vermicompost, solid	Solid	7.04	39.68	2.9	2.74	1.06
Vermicompost, liquid	Liquid	7.9	10.8	2.1	0.26	0.11
Commercial organic fertilizer	Solid	3.1–5.1	80.0	8.0	–	–

OM (organic matter). The bacterial biofertilizer was a liquid formulation containing 5×10^8 live cells of a bacterial consortium (*Azospirillum brasilense*, *Azotobacter vinelandii*, *A. chroococcum*, *Rhizobium trifolii*, *Pseudomonas fluorescens*, *Bacillus subtilis*, *B. licheniformis*, *B. amyloliquefaciens*, *B. mucilaginosus*). N values for compost, commercial fertilizer, and the biofertilizer represent organic N as declared by the manufacturer; dashes indicate values not declared.

Yield and fruit measurements

Clusters were harvested at commercial maturity (TSS ≥ 18 °Brix in the bulk sample) and yield per vine was recorded; area-based yield was calculated from vine density and expressed as t ha⁻¹. For each vine, five representative clusters were weighed to obtain mean cluster weight, and cluster width and length were measured with a ruler; cluster size was computed as the product of width and length. Berry measurements were made on 100 berries sampled from the middle third of each vine: the volume of 100 berries was determined with a graduated cylinder and their weight on a precision balance, and the width and length of 10 randomly selected berries were measured with a digital caliper, with berry size calculated as the product of width and length. Must was obtained by hand-pressing berries through

cheesecloth; total soluble solids (TSS, %) were measured with a digital refractometer, pH with a pH meter, and titratable acidity by titration with 0.1 N NaOH to pH 8.2 and expressed as g tartaric acid L⁻¹.

Leaf nutrient analysis

Leaf blades were sampled at veraison, washed successively with tap water, distilled water, 0.1% HCl and twice with distilled water, dried at 65°C for 72 h and ground in an agate mill. Nitrogen was determined by the Kjeldahl method; phosphorus colorimetrically after dry-ashing at 550°C and dissolution in 1:3 HCl; and K, Ca, Mg, Fe, Zn, Cu, Mn and B by atomic-absorption spectrometry on the same dry-ashed extracts. Concentrations were evaluated against published sufficiency ranges for grapevine and are reported as single determinations on pooled samples per treatment; no formal statistical analysis of leaf nutrient data was therefore conducted.

Statistical analysis

Data on yield, cluster and berry traits and must composition were subjected to one-way analysis of variance appropriate to a randomized complete block design, and treatment means were compared by Tukey's honestly significant difference test at $p \leq 0.05$. Because the experimental design comprised three replicates, only differences of substantial magnitude could be detected; the analysis should therefore be interpreted as exploratory. All analyses were performed in SPSS (v. 22.0; IBM Corp., Armonk, NY, USA).

Results

Yield and cluster traits

Analysis of variance detected no significant differences among treatments for yield or for any cluster trait ($p > 0.05$). Vine yield ranged from 7.07 kg vine⁻¹ under soil-applied commercial fertilizer at 50 g to 15.22 kg vine⁻¹ under the bacterial biofertilizer at 100 mL, and area-based yield from 11.73 to 25.27 t ha⁻¹ over the same treatments, the maxima occurring under the bacterial biofertilizer at 100 mL (Table 3). The untreated control yielded 11.10 kg vine⁻¹. Cluster weight varied between 152.85 g under soil-applied commercial fertilizer at 50 g and 289.82 g under liquid compost at 75 mL (Table 4). The widest clusters were recorded under solid vermicompost at 2.5 kg (14.43 cm) and the longest under solid vermicompost at 2.0 kg (18.20 cm), which also produced the largest cluster size (220.15 cm²). Standard errors were large relative to treatment means for several traits; cluster weight under farmyard manure at 1.8 kg, for example, carried a standard error of 65.44 g on a mean of 233.44 g.

Table 3
Effect of organic fertilizer treatments on the yield of 'Boğazkere'
grapevine (mean $\pm$ SE, n = 3).

Treatment	Vine yield (kg vine⁻¹)	Yield (t ha⁻¹)
Mycorrhiza 50 cc	11.04 $\pm$ 0.49	18.32 $\pm$ 0.83
Mycorrhiza 100 cc	15.22 $\pm$ 4.38	25.27 $\pm$ 7.27
Mycorrhiza 150 cc	9.37 $\pm$ 1.23	15.56 $\pm$ 2.05
Bat manure 400 cc	8.07 $\pm$ 2.03	13.40 $\pm$ 3.37
Bat manure 500 cc	11.02 $\pm$ 3.73	18.29 $\pm$ 6.19
Bat manure 600 cc	8.78 $\pm$ 2.15	14.57 $\pm$ 3.57
Farmyard manure 0.6 kg	11.04 $\pm$ 1.25	18.33 $\pm$ 2.08
Farmyard manure 1.2 kg	8.54 $\pm$ 2.04	14.18 $\pm$ 3.40
Farmyard manure 1.8 kg	12.88 $\pm$ 4.03	21.38 $\pm$ 6.71
Compost, solid 0.5 kg	8.90 $\pm$ 2.75	14.78 $\pm$ 4.57
Compost, solid 1.0 kg	10.97 $\pm$ 1.11	18.21 $\pm$ 1.85
Compost, solid 1.5 kg	11.90 $\pm$ 2.96	19.75 $\pm$ 4.93
Compost, liquid 25 cc	10.03 $\pm$ 2.66	16.66 $\pm$ 4.43
Compost, liquid 50 cc	9.80 $\pm$ 0.52	16.27 $\pm$ 0.88
Compost, liquid 75 cc	13.21 $\pm$ 3.17	21.93 $\pm$ 5.26
Vermicompost, solid 1.5 kg	10.75 $\pm$ 2.09	17.84 $\pm$ 3.47
Vermicompost, solid 2.0 kg	12.69 $\pm$ 3.82	21.06 $\pm$ 6.35
Vermicompost, solid 2.5 kg	11.83 $\pm$ 1.44	19.63 $\pm$ 2.39
Vermicompost, liquid 25 cc	12.00 $\pm$ 1.13	19.92 $\pm$ 1.88
Vermicompost, liquid 50 cc	11.32 $\pm$ 0.67	18.78 $\pm$ 1.13
Vermicompost, liquid 75 cc	10.88 $\pm$ 0.80	18.07 $\pm$ 1.33
Commercial, soil 50 g	7.07 $\pm$ 0.81	11.73 $\pm$ 1.36
Commercial, soil 100 g	9.96 $\pm$ 2.44	16.53 $\pm$ 4.06
Commercial, soil 150 g	10.63 $\pm$ 2.08	17.64 $\pm$ 3.46
Commercial, foliar 10 g	14.15 $\pm$ 3.55	23.49 $\pm$ 5.90
Commercial, foliar 15 g	10.71 $\pm$ 2.82	17.78 $\pm$ 4.68

Treatment	Vine yield (kg vine ⁻¹)	Yield (t ha ⁻¹)
Commercial, foliar 20 g	11.42 ± 3.22	18.96 ± 5.36
Control	11.10 ± 2.72	18.43 ± 4.53

Differences among treatments were not significant ($p > 0.05$).

Table 4
Effect of organic fertilizer treatments on cluster traits of 'Boğazkere' grapevine (mean $\pm$ SE, n = 3).

Treatment	Cluster weight (g)	Cluster width (cm)	Cluster length (cm)	Cluster size (cm ²)
Mycorrhiza 50 cc	187.20 $\pm$ 7.46	9.36 $\pm$ 0.13	16.93 $\pm$ 0.69	158.67 $\pm$ 7.61
Mycorrhiza 100 cc	277.22 $\pm$ 32.68	11.50 $\pm$ 0.28	17.77 $\pm$ 1.17	204.98 $\pm$ 18.71
Mycorrhiza 150 cc	209.65 $\pm$ 33.67	11.63 $\pm$ 1.44	15.00 $\pm$ 0.96	173.74 $\pm$ 20.94
Bat manure 400 cc	212.39 $\pm$ 8.73	11.13 $\pm$ 0.76	17.76 $\pm$ 0.33	197.33 $\pm$ 10.90
Bat manure 500 cc	211.13 $\pm$ 27.14	10.62 $\pm$ 0.74	17.93 $\pm$ 0.72	189.72 $\pm$ 10.46
Bat manure 600 cc	168.76 $\pm$ 13.44	10.13 $\pm$ 1.06	16.97 $\pm$ 0.33	171.94 $\pm$ 18.83
Farmyard manure 0.6 kg	199.43 $\pm$ 2.29	11.56 $\pm$ 0.57	17.66 $\pm$ 1.14	203.10 $\pm$ 4.45
Farmyard manure 1.2 kg	189.61 $\pm$ 25.08	10.26 $\pm$ 0.28	16.60 $\pm$ 1.88	171.24 $\pm$ 22.83
Farmyard manure 1.8 kg	233.44 $\pm$ 65.44	11.10 $\pm$ 1.84	13.77 $\pm$ 2.22	157.39 $\pm$ 47.18
Compost, solid 0.5 kg	214.44 $\pm$ 14.48	10.22 $\pm$ 1.27	17.00 $\pm$ 0.45	174.94 $\pm$ 25.74
Compost, solid 1.0 kg	179.99 $\pm$ 22.84	10.56 $\pm$ 0.62	15.26 $\pm$ 0.26	161.01 $\pm$ 6.81
Compost, solid 1.5 kg	194.84 $\pm$ 28.74	10.13 $\pm$ 1.22	16.23 $\pm$ 1.50	167.62 $\pm$ 35.51
Compost, liquid 25 cc	183.00 $\pm$ 33.17	9.20 $\pm$ 0.91	16.20 $\pm$ 2.65	153.76 $\pm$ 41.38
Compost, liquid 50 cc	228.60 $\pm$ 37.74	10.50 $\pm$ 0.61	18.09 $\pm$ 1.39	190.17 $\pm$ 20.17
Compost, liquid 75 cc	289.82 $\pm$ 40.74	12.97 $\pm$ 0.52	16.20 $\pm$ 4.17	212.14 $\pm$ 56.92
Vermicompost, solid 1.5 kg	214.05 $\pm$ 14.32	10.74 $\pm$ 0.85	15.54 $\pm$ 0.37	166.42 $\pm$ 9.75
Vermicompost, solid 2.0 kg	213.88 $\pm$ 8.34	12.04 $\pm$ 0.62	18.20 $\pm$ 0.80	220.15 $\pm$ 20.55
Vermicompost, solid 2.5 kg	249.42 $\pm$ 42.22	14.43 $\pm$ 0.34	17.23 $\pm$ 1.53	196.67 $\pm$ 16.79
Vermicompost, liquid 25 cc	206.25 $\pm$ 18.22	10.77 $\pm$ 0.17	15.43 $\pm$ 0.43	166.14 $\pm$ 4.88
Vermicompost, liquid 50 cc	275.68 $\pm$ 53.88	11.90 $\pm$ 0.70	18.13 $\pm$ 1.09	216.62 $\pm$ 22.38
Vermicompost, liquid 75 cc	237.93 $\pm$ 43.00	11.10 $\pm$ 0.62	17.14 $\pm$ 1.08	190.45 $\pm$ 16.93
Commercial, soil 50 g	152.85 $\pm$ 4.96	8.56 $\pm$ 0.33	15.13 $\pm$ 0.60	129.97 $\pm$ 9.73

Treatment	Cluster weight (g)	Cluster width (cm)	Cluster length (cm)	Cluster size (cm ²)
Commercial, soil 100 g	222.58 ± 24.81	10.36 ± 0.61	16.49 ± 0.66	169.47 ± 4.35
Commercial, soil 150 g	188.01 ± 17.89	9.97 ± 0.69	15.33 ± 0.95	152.03 ± 9.31
Commercial, foliar 10 g	211.45 ± 12.94	10.00 ± 0.47	17.06 ± 1.06	171.63 ± 18.96
Commercial, foliar 15 g	237.13 ± 49.16	11.46 ± 1.02	16.00 ± 2.33	187.87 ± 44.65
Commercial, foliar 20 g	246.20 ± 48.98	10.71 ± 0.77	16.97 ± 1.18	183.29 ± 24.12
Control	198.72 ± 25.97	10.00 ± 0.71	16.30 ± 0.47	163.61 ± 15.17

Differences among treatments were not significant ($p > 0.05$).

Berry traits

Berry traits likewise showed no significant treatment effects ($p > 0.05$). The volume of 100 berries ranged from 20.00 to 33.33 mL, the latter under soil-applied commercial fertilizer at 150 g, corresponding to a 42.9% numerical increase over the control. The weight of 100 berries varied between 187.80 g under bat manure at 500 mL and 289.62 g under the bacterial biofertilizer at 100 mL, the latter representing a 29.0% increase over the control value of 224.47 g. Berry width, berry length and berry size all reached their maximum under the bacterial biofertilizer at 100 mL (16.04 mm, 17.56 mm and 284.73 mm², respectively), with berry size exceeding the control by 9.9% (Table 5). The same treatment nevertheless carried the largest standard error for the weight of 100 berries (± 74.65 g), so this apparent advantage rests on a wide dispersion among replicates.

Table 5
Effect of organic fertilizer treatments on berry traits of 'Boğazkere' grapevine (mean $\pm$ SE, n = 3).

Treatment	100-Berry volume (mL)	100-Berry weight (g)	Berry width (mm)	Berry length (mm)	Berry size (mm ²)
Mycorrhiza 50 mL	23.33 $\pm$ 0.33	204.31 $\pm$ 13.09	13.54 $\pm$ 0.43	14.90 $\pm$ 0.74	202.38 $\pm$ 16.77
Mycorrhiza 100 mL	30.00 $\pm$ 0.57	289.62 $\pm$ 74.65	16.04 $\pm$ 1.47	17.56 $\pm$ 1.10	284.73 $\pm$ 44.91
Mycorrhiza 150 mL	23.66 $\pm$ 0.33	208.58 $\pm$ 20.26	13.52 $\pm$ 1.28	15.23 $\pm$ 0.98	208.43 $\pm$ 32.02
Bat manure 400 mL	20.00 $\pm$ 0.00	201.18 $\pm$ 11.71	13.61 $\pm$ 0.39	15.13 $\pm$ 0.18	206.11 $\pm$ 8.51
Bat manure 500 mL	23.33 $\pm$ 0.33	187.80 $\pm$ 11.84	14.04 $\pm$ 0.39	15.57 $\pm$ 0.31	218.89 $\pm$ 10.57
Bat manure 600 mL	23.33 $\pm$ 0.33	216.82 $\pm$ 24.62	14.54 $\pm$ 0.85	15.93 $\pm$ 0.78	232.94 $\pm$ 25.49
Farmyard manure 0.6 kg	26.66 $\pm$ 0.33	202.46 $\pm$ 4.33	13.91 $\pm$ 0.19	15.91 $\pm$ 0.25	221.90 $\pm$ 4.47
Farmyard manure 1.2 kg	30.00 $\pm$ 0.57	208.94 $\pm$ 21.17	14.18 $\pm$ 1.45	16.90 $\pm$ 1.07	242.65 $\pm$ 40.18
Farmyard manure 1.8 kg	23.33 $\pm$ 0.33	216.66 $\pm$ 9.01	14.94 $\pm$ 0.12	16.02 $\pm$ 0.31	239.24 $\pm$ 3.91
Compost, solid 0.5 kg	23.33 $\pm$ 0.33	230.70 $\pm$ 6.93	13.95 $\pm$ 0.44	15.90 $\pm$ 0.98	222.60 $\pm$ 21.12
Compost, solid 1.0 kg	23.33 $\pm$ 0.33	203.35 $\pm$ 11.68	13.69 $\pm$ 0.37	14.79 $\pm$ 0.55	202.66 $\pm$ 12.22
Compost, solid 1.5 kg	20.00 $\pm$ 0.00	204.63 $\pm$ 7.90	14.40 $\pm$ 0.40	15.80 $\pm$ 0.37	227.86 $\pm$ 11.74
Compost, liquid 25 mL	23.33 $\pm$ 0.67	216.93 $\pm$ 18.01	13.21 $\pm$ 0.83	15.67 $\pm$ 0.50	207.70 $\pm$ 19.37
Compost, liquid 50 mL	26.66 $\pm$ 0.33	235.97 $\pm$ 15.59	14.47 $\pm$ 0.80	15.90 $\pm$ 0.42	237.07 $\pm$ 17.71
Compost, liquid 75 mL	26.66 $\pm$ 0.33	223.94 $\pm$ 9.57	14.75 $\pm$ 0.20	16.65 $\pm$ 0.20	245.58 $\pm$ 2.11
Vermicompost, solid 1.5 kg	23.33 $\pm$ 0.33	215.33 $\pm$ 26.19	14.27 $\pm$ 0.38	16.09 $\pm$ 0.36	229.94 $\pm$ 11.43
Vermicompost, solid 2.0 kg	23.33 $\pm$ 0.33	200.88 $\pm$ 16.02	13.90 $\pm$ 0.43	15.87 $\pm$ 0.66	221.10 $\pm$ 15.56

Treatment	100-Berry volume (mL)	100-Berry weight (g)	Berry width (mm)	Berry length (mm)	Berry size (mm ²)
Vermicompost, solid 2.5 kg	30.00 ± 0.00	214.00 ± 15.03	13.54 ± 1.04	15.11 ± 1.05	206.56 ± 30.13
Vermicompost, liquid 25 mL	26.66 ± 0.33	224.21 ± 12.52	14.76 ± 0.70	16.13 ± 0.86	239.13 ± 23.43
Vermicompost, liquid 50 mL	20.00 ± 0.00	223.15 ± 12.65	14.77 ± 0.32	16.06 ± 0.55	237.59 ± 13.05
Vermicompost, liquid 75 mL	26.66 ± 0.33	234.31 ± 28.57	14.82 ± 1.42	16.88 ± 1.08	253.29 ± 41.15
Commercial, soil 50 g	26.66 ± 0.33	201.98 ± 14.19	13.97 ± 0.43	15.38 ± 0.34	215.15 ± 10.93
Commercial, soil 100 g	23.33 ± 0.33	205.46 ± 9.88	13.56 ± 0.77	15.24 ± 0.48	207.23 ± 18.41
Commercial, soil 150 g	33.33 ± 0.33	259.74 ± 18.19	15.17 ± 0.89	16.38 ± 0.91	250.13 ± 27.78
Commercial, foliar 10 g	23.33 ± 0.33	204.74 ± 23.44	13.60 ± 0.76	15.70 ± 0.76	214.62 ± 22.09
Commercial, foliar 15 g	23.33 ± 0.33	214.72 ± 5.39	13.52 ± 0.07	14.96 ± 0.26	202.22 ± 4.11
Commercial, foliar 20 g	23.33 ± 0.33	219.51 ± 10.64	14.83 ± 0.25	16.14 ± 0.52	236.10 ± 11.53
Control	23.33 ± 0.33	224.47 ± 16.47	15.36 ± 0.85	16.83 ± 0.33	259.16 ± 19.39

Differences among treatments were not significant ($p > 0.05$).

Must composition

Total soluble solids was the only must trait that approached significance among treatments ($p = 0.07$; $p < 0.10$; Table 6). The highest value, 19.43%, was recorded under the bacterial biofertilizer at 100 mL and the lowest, 16.63%, under liquid compost at 75 mL, with foliar commercial fertilizer at 10 g close behind at 16.87%; relative to the control (18.10%), the bacterial biofertilizer at 100 mL represents an increase of 7.3%. Soil-applied commercial fertilizer at 150 g gave 19.00% and farmyard manure at 1.2 kg gave 18.97%. Must pH ranged from 3.23 under farmyard manure at 0.6 kg and solid vermicompost at 2.0 kg to 3.53 under liquid compost at 25 mL, and titratable acidity from 0.92 g L⁻¹ under solid compost at 1.5 kg to 1.30 g L⁻¹ under liquid vermicompost at 75 mL, the latter exceeding the control (1.06 g L⁻¹) by 22.6%. Neither pH nor titratable acidity differed significantly among treatments ($p > 0.05$).

Table 6

Effect of organic fertilizer treatments on must composition of 'Boğazkere' grapevine (mean $\pm$ SE, n = 3).

Treatment	pH	TSS (%)	Titrateable acidity (g L ⁻¹)
Mycorrhiza 50 mL	3.36 $\pm$ 0.08	17.43 $\pm$ 0.03 ab	0.96 $\pm$ 0.04
Mycorrhiza 100 mL	3.43 $\pm$ 0.04	19.43 $\pm$ 0.40 b	1.11 $\pm$ 0.03
Mycorrhiza 150 mL	3.37 $\pm$ 0.10	17.10 $\pm$ 0.20 ab	1.18 $\pm$ 0.04
Bat manure 400 mL	3.32 $\pm$ 0.02	17.53 $\pm$ 0.08 ab	1.18 $\pm$ 0.17
Bat manure 500 mL	3.34 $\pm$ 0.12	17.37 $\pm$ 0.06 ab	1.14 $\pm$ 0.05
Bat manure 600 mL	3.37 $\pm$ 0.02	17.63 $\pm$ 0.83 ab	1.12 $\pm$ 0.06
Farmyard manure 0.6 kg	3.23 $\pm$ 0.04	17.87 $\pm$ 0.14 ab	0.96 $\pm$ 0.02
Farmyard manure 1.2 kg	3.38 $\pm$ 0.15	18.97 $\pm$ 0.38 ab	1.27 $\pm$ 0.13
Farmyard manure 1.8 kg	3.31 $\pm$ 0.07	18.43 $\pm$ 0.49 ab	1.06 $\pm$ 0.02
Compost, solid 0.5 kg	3.39 $\pm$ 0.02	17.87 $\pm$ 0.55 ab	1.26 $\pm$ 0.02
Compost, solid 1.0 kg	3.36 $\pm$ 0.04	17.50 $\pm$ 0.45 ab	1.09 $\pm$ 0.02
Compost, solid 1.5 kg	3.33 $\pm$ 0.04	17.87 $\pm$ 0.34 ab	0.92 $\pm$ 0.05
Compost, liquid 25 mL	3.53 $\pm$ 0.06	17.67 $\pm$ 0.42 ab	1.00 $\pm$ 0.02
Compost, liquid 50 mL	3.44 $\pm$ 0.01	18.53 $\pm$ 0.41 ab	1.09 $\pm$ 0.03
Compost, liquid 75 mL	3.43 $\pm$ 0.04	16.63 $\pm$ 0.46 a	1.16 $\pm$ 0.31
Vermicompost, solid 1.5 kg	3.46 $\pm$ 0.03	18.07 $\pm$ 0.26 ab	1.06 $\pm$ 0.06
Vermicompost, solid 2.0 kg	3.23 $\pm$ 0.03	17.67 $\pm$ 0.12 ab	1.23 $\pm$ 0.16
Vermicompost, solid 2.5 kg	3.30 $\pm$ 0.04	17.20 $\pm$ 0.43 ab	1.17 $\pm$ 0.12
Vermicompost, liquid 25 mL	3.29 $\pm$ 0.02	17.13 $\pm$ 0.57 ab	1.02 $\pm$ 0.06
Vermicompost, liquid 50 mL	3.34 $\pm$ 0.05	17.73 $\pm$ 0.84 ab	1.04 $\pm$ 0.09
Vermicompost, liquid 75 mL	3.35 $\pm$ 0.02	17.97 $\pm$ 0.58 ab	1.30 $\pm$ 0.26
Commercial, soil 50 g	3.30 $\pm$ 0.02	17.73 $\pm$ 0.56 ab	1.06 $\pm$ 0.02
Commercial, soil 100 g	3.28 $\pm$ 0.07	17.80 $\pm$ 0.15 ab	1.05 $\pm$ 0.11
Commercial, soil 150 g	3.34 $\pm$ 0.04	19.00 $\pm$ 0.10 ab	1.14 $\pm$ 0.12
Commercial, foliar 10 g	3.27 $\pm$ 0.10	16.87 $\pm$ 0.14 a	1.00 $\pm$ 0.09
Commercial, foliar 15 g	3.33 $\pm$ 0.15	18.06 $\pm$ 0.63 ab	1.16 $\pm$ 0.05

Treatment	pH	TSS (%)	Titrateable acidity (g L ⁻¹)
Commercial, foliar 20 g	3.36 ± 0.06	18.23 ± 0.64 ab	1.12 ± 0.10
Control	3.44 ± 0.05	18.10 ± 0.30 ab	1.06 ± 0.00

Within the TSS column, means followed by different letters differ according to Tukey's test; the ANOVA for TSS was significant only at $p < 0.10$ (see Materials and Methods). Differences in pH and titrateable acidity were not significant.

Leaf nutrient concentrations

Leaf N ranged from 2.14 to 2.38% and thus remained within the published sufficiency range in every treatment, with the highest value under liquid vermicompost at 75 mL. Leaf K varied from 0.75 to 1.27%, with the maximum under solid vermicompost at 2.0 kg, and leaf P from 0.08 to 0.16%, the maximum under foliar commercial fertilizer at 20 g (Table 7). The control recorded a leaf P of 0.09%. Among micronutrients, leaf Fe ranged from 189 mg kg⁻¹ in the control to 429 mg kg⁻¹ under foliar commercial fertilizer at 10 g, representing a 127% numerical increase. Leaf Mn varied between 76 mg kg⁻¹ under bat manure at 600 mL and 143 mg kg⁻¹ under bat manure at 500 mL, remaining within the sufficiency range of 30–300 mg kg⁻¹ throughout (Table 8). Leaf Zn ranged from 10 to 19 mg kg⁻¹ and fell below the published sufficiency threshold in all treatments, including the control; the highest value, 19 mg kg⁻¹, was shared by bat manure at 600 mL, foliar commercial fertilizer at 10 g, and the control.

Table 7
Leaf macronutrient concentrations of 'Boğazkere' grapevine under organic
fertilizer treatments.

Treatment	N (%)	K (%)	P (%)	Ca (%)	Mg (%)
Mycorrhiza 50 mL	2.34	0.98	0.10	2.94	0.46
Mycorrhiza 100 mL	2.37	0.86	0.12	2.79	0.40
Mycorrhiza 150 mL	2.34	0.77	0.10	3.21	0.49
Bat manure 400 mL	2.36	0.80	0.10	2.82	0.43
Bat manure 500 mL	2.34	0.81	0.08	3.20	0.53
Bat manure 600 mL	2.20	1.24	0.10	2.58	0.45
Farmyard manure 0.6 kg	2.27	0.83	0.10	2.78	0.51
Farmyard manure 1.2 kg	2.26	1.01	0.11	2.70	0.34
Farmyard manure 1.8 kg	2.27	0.77	0.10	3.05	0.47
Compost, solid 0.5 kg	2.21	0.82	0.10	2.69	0.39
Compost, solid 1.0 kg	2.18	0.80	0.10	2.89	0.57
Compost, solid 1.5 kg	2.21	1.04	0.10	3.19	0.46
Compost, liquid 25 mL	2.32	0.81	0.13	2.76	0.42
Compost, liquid 50 mL	2.14	0.83	0.14	2.86	0.45
Compost, liquid 75 mL	2.26	0.81	0.14	2.86	0.52
Vermicompost, solid 1.5 kg	2.28	0.78	0.10	2.82	0.48
Vermicompost, solid 2.0 kg	2.36	1.27	0.11	2.51	0.44
Vermicompost, solid 2.5 kg	2.27	0.82	0.10	3.19	0.48
Vermicompost, liquid 25 mL	2.21	0.80	0.10	2.86	0.44
Vermicompost, liquid 50 mL	2.18	0.99	0.11	2.76	0.47
Vermicompost, liquid 75 mL	2.38	0.94	0.09	3.18	0.48
Commercial, soil 50 g	2.16	0.75	0.10	2.87	0.45
Commercial, soil 100 g	2.32	0.83	0.10	3.06	0.55
Commercial, soil 150 g	2.18	1.08	0.10	2.94	0.46
Commercial, foliar 10 g	2.28	0.86	0.13	3.00	0.46
Commercial, foliar 15 g	2.24	0.86	0.13	3.01	0.48

Treatment	N (%)	K (%)	P (%)	Ca (%)	Mg (%)
Commercial, foliar 20 g	2.26	0.89	0.16	3.16	0.53
Control	2.28	1.14	0.09	2.70	0.42

Values are single determinations on pooled samples per treatment; see Materials and Methods.

Table 8

Leaf micronutrient concentrations of 'Boğazkere' grapevine under organic fertilizer treatments.

Treatment	Fe (mg kg⁻¹)	Zn (mg kg⁻¹)	Mn (mg kg⁻¹)	Cu (mg kg⁻¹)	B (mg kg⁻¹)
Mycorrhiza 50 mL	243	14	119	4	30
Mycorrhiza 100 mL	194	14	94	4	31
Mycorrhiza 150 mL	220	13	113	4	34
Bat manure 400 mL	217	15	102	4	40
Bat manure 500 mL	262	11	143	4	30
Bat manure 600 mL	245	19	76	4	35
Farmyard manure 0.6 kg	249	10	111	4	29
Farmyard manure 1.2 kg	299	14	86	4	36
Farmyard manure 1.8 kg	287	11	101	4	29
Compost, solid 0.5 kg	229	10	94	3	37
Compost, solid 1.0 kg	193	17	118	4	33
Compost, solid 1.5 kg	308	11	100	4	27
Compost, liquid 25 mL	289	15	89	4	27
Compost, liquid 50 mL	260	16	103	5	48
Compost, liquid 75 mL	311	16	88	4	37
Vermicompost, solid 1.5 kg	222	11	81	4	36
Vermicompost, solid 2.0 kg	215	16	109	4	35
Vermicompost, solid 2.5 kg	253	18	115	4	42
Vermicompost, liquid 25 mL	422	11	82	4	32
Vermicompost, liquid 50 mL	261	13	108	4	26
Vermicompost, liquid 75 mL	319	12	115	4	38
Commercial, soil 50 g	243	10	95	3	31
Commercial, soil 100 g	252	14	113	4	28

Treatment	Fe (mg kg ⁻¹)	Zn (mg kg ⁻¹)	Mn (mg kg ⁻¹)	Cu (mg kg ⁻¹)	B (mg kg ⁻¹)
Commercial, soil 150 g	252	14	92	4	26
Commercial, foliar 10 g	429	19	95	4	31
Commercial, foliar 15 g	298	16	103	4	36
Commercial, foliar 20 g	378	16	123	4	39
Control	189	19	105	4	34

Values are single determinations on pooled samples per treatment; see Materials and Methods.

Discussion

Sugar accumulation was the only first-season response detected

Among the traits examined, only total soluble solids separated among treatments, with the maximum value recorded under the bacterial biofertilizer at 100 mL. The interpretation we favour rests on the nutritional status of the experimental soil: available P was low at all three depths sampled, available Zn was likewise low, and free CaCO₃ reached 16.7% in the topsoil – a combination that keeps both elements in sparingly soluble forms (Marschner 2012; Naseer and Muhammad 2014). The nitrogen-fixing and phosphate-solubilizing bacteria in the biofertilizer mobilise such calcium-bound phosphate by acidifying the rhizosphere through organic-acid release, a mechanism whose effect is greatest precisely on calcareous soils of this kind (Alori et al. 2017), and comparable consortia have alleviated alkaline stress and promoted growth in grapevine (Karaca and Sabir 2017; Lu et al. 2020). Consistent with improved P acquisition, leaf P under the biofertilizer at 100 mL (0.12%) exceeded that of the control (0.09%), although the pooled-sample nature of the leaf data precludes a formal test. The increase in must TSS is in line with the view that microbial inoculants hasten sugar accumulation in grape berries through the promotion of nutrient uptake and the stimulation of photosynthetic activity (Torres et al. 2018), a response documented to vary by cultivar, inoculant and seasonal conditions (Ganugi et al. 2023); leaf-P increases of up to 42% have been reported for mycorrhizal inoculation of grapevine (Peng et al. 2025). The principal physiological driver of sugar accumulation in grape berries is the shift from symplasmic to apoplastic phloem unloading that becomes operative at or just before véraison (Zhang et al. 2006), once sugar import is no longer limited to plasmodesmatal pathways (Lu et al. 2024). Phosphorus governs this transition, because low P diminishes sucrose-phosphate synthase activity and sucrose export from source leaves, redirecting photosynthate to root starch and limiting sugar loading into the berry (Fredeen et al. 1989). A rise in must TSS is therefore the response that would be expected to appear first in a nutrient-limited system, before any change in yield or berry morphology becomes detectable.

Organic matter-based amendments did not act within one season

Farmyard manure, compost and vermicompost left yield, cluster and berry traits unchanged. Two conditions of the experiment account for this. First, these materials release nutrients through microbial mineralisation, a process that requires soil moisture. The summer months at this site are effectively rainless, so microbial activity in the amended root zone would have been suppressed during the period when vine demand was highest. Second, the soil already carried high exchangeable K and Ca and sufficient total N, leaving little scope for a nutrient-mediated response to materials whose principal contribution is bulk organic matter. Reports of positive effects in vineyards are consistent with this reading because they came from experiments in which the amendment acted over more than one season or was placed deep in the profile. Gaiotti et al. (2017) recorded changes in root growth and vine performance in Cabernet Sauvignon only after repeated compost application, and Badalíková et al. (2022) obtained yield and quality effects only after deep placement of compost into the vineyard soil; Mairata et al. (2024) similarly attributed improvements in grape composition on nutrient-poor soils to the cumulative action of organic mulches across multiple seasons. Our findings do not contradict these studies; they delimit the time scale over which such effects emerge. The longest direct test of this question is the 28-year field experiment of Morlat on a calcareous sandy soil in Chinon, France, in which significant effects of organic amendments on root system, yield and foliar nutrient status appeared only 14 years after the start of the trial (Morlat 2008; Morlat and Chaussod 2008). In Geisenheim, Germany, an 18-year comparison of organic, biodynamic and integrated management in a Riesling vineyard showed that organic and biodynamic systems initially yielded 14–17% lower than integrated and only closed that gap 8–9 years after conversion (Döring et al. 2026). Even where compost or biochar was incorporated at depth in a single season in a 'Calardis Musqué' vineyard, vine balance and juice composition remained unchanged, confirming that a single high-dose incorporation event is not enough to alter berry composition when mineralisable N is not released during the ripening window (Schneider et al. 2023).

Bat manure followed the same pattern

Bat guano is chemically heterogeneous, its mineral composition varying with bat species, diet and cave geology. Insectivorous guano from *Hipposideros speoris*, for example, contains high total N (> 7.6%) and phosphate (Sridhar et al. 2006); analyses of guano from multi-source deposits have reported pH in the range 4.0–8.5 depending on maturity, with C/N ratios between 8 and 15 (Abd Rahman et al. 2023; Marwa et al. 2021). Under tropical sandy-soil conditions guano can mineralise rapidly enough to behave more like a mineral fertiliser than a conventional farmyard manure (Dimande et al. 2023). In our study this did not happen, presumably because mineralisation is moisture-dependent in the same way that it is for compost and farmyard manure; under the effectively rainless summer of the experimental season, even a fast-cycling guano would have remained locked in the substrate. The leaf nutrient data, in which leaf N did not differ in any meaningful way among bat manure rates and the control, are consistent with this reading.

Reserve carbohydrates constrain first-season yield responses

Yield in a mature vine is determined largely by bud fruitfulness established in the preceding season (Vasconcelos et al. 2009) and by non-structural carbohydrate reserves stored in the permanent structure, mainly in roots and perennial wood (Martínez-Lüscher and Kurtural 2021; Pellegrino et al. 2014). A nutrient supply applied in spring therefore acts on a crop whose size has already been set, and its effect appears chiefly in traits formed later in the season, such as berry composition. This mechanism explains why TSS responded while yield and cluster traits did not, and it also explains the wide standard errors observed for several traits: variation among individual vines in reserve status is carried directly into the measured means and can exceed the treatment effect (Martínez-Lüscher and Kurtural 2021). The magnitude of this dispersion in the present data, exemplified by a standard error of 74.65 g on a mean of 289.62 g for the weight of 100 berries under the bacterial biofertilizer at 100 mL, indicates that a single season with three replicates provides limited statistical power to detect moderate treatment effects.

Zinc deficiency was not corrected by any treatment

Leaf Zn remained below the published sufficiency threshold ($10\text{--}19\text{ mg kg}^{-1}$) in every treatment, including those supplying the largest amounts of organic material. This is consistent with the soil analysis, which classified available Zn as low at all depths, and with the high CaCO_3 content of the site. Zinc availability declines sharply as soil pH rises above 7.5, both because Zn solubility decreases per unit increase in pH and because CaCO_3 forms insoluble complexes with Zn (Marschner 2012). On calcareous soils foliar Zn application is more effective than soil application (Zhao et al. 2014), and the result carries a practical implication for organic vineyards in the region: Zn deficiency will not be resolved by organic amendment alone and calls for a targeted foliar Zn programme. The elevated leaf Fe recorded under the foliar commercial fertilizer at 10 g (429 mg kg^{-1} against 189 mg kg^{-1} in the control, a numerical increase of 127%) shows that foliar delivery can raise leaf micronutrient concentration at this site, and is consistent with reports that combined EDDHA-Fe, Zn and Mn sprays increased leaf Fe and growth of *V. vinifera* on calcareous soils of north-western Iran (Mohebbi et al. 2022); the absence of a comparable Zn response suggests, however, that the product used here was not an effective Zn source. The most informative reference points for the corrective strategy are the foliar-Zn studies on *Vitis vinifera*: on 'Syrah', ZnSO_4 or ZnO sprays raised berry Zn without reaching toxicity (Daccak et al. 2024), while on 'Castelão' and 'Moscatel' the same active ingredients elevated berry Zn 1.0- to 8.4-fold and lifted Zn in the resultant wine 1.3- to 3.6-fold (Daccak et al. 2022). Effectiveness of foliar Zn on grapevine is in turn determined by spray volume and Zn source: dilute full-wetting applications consistently outperformed concentrate sprays, and a Zn-EDTA chelate at $0.56\text{ kg Zn ha}^{-1}$ matched basic zinc sulphate at $2.24\text{ kg Zn ha}^{-1}$ in raising shoot-tip Zn 10–14 days after application (Christensen and Jensen 1978). On our site a dedicated foliar Zn strategy, using ZnSO_4 or a Zn-EDTA formulation with full-wetting coverage, appears to be required rather than continued reliance on the commercial product used here, which raised leaf Fe but not Zn.

Limitations

The experiment covered a single growing season at one location with one cultivar; leaf nutrient data were single determinations on pooled samples, precluding statistical inference on nutrient concentrations; only three replicates, each of three vines, were available, which limited the statistical power to detect effects of moderate magnitude. The absence of significant differences for yield and fruit traits should therefore be read as a failure to detect an effect under these conditions rather than as evidence that no effect exists. Soil chemical properties were characterised only before the experiment, so the extent to which the amendments altered soil pH, organic carbon or available P during the season is unknown; measuring these variables at the end of each season would allow the mechanism proposed here to be tested directly. Repetition over at least two further seasons, with end-of-season soil and leaf sampling, is required before the treatments can be ranked with confidence. Long-term trials in organic viticulture confirm that single-season evaluations are a serious constraint on inference: in the Geisenheim 18-year comparison the organic and biodynamic systems needed approximately a decade to close the initial yield gap with integrated management (Döring et al. 2026), and the 28-year Loire Valley trial required 14 years before root-system and foliar effects of organic amendments became significant (Morlat 2008).

Conclusions

On a calcareous, phosphorus- and zinc-deficient vineyard soil under semi-arid conditions, a single season of organic fertilisation left yield, cluster and berry morphology of mature 'Boğazkere' vines unchanged. The bacterial biofertilizer at 100 mL vine⁻¹ raised must total soluble solids by 7.3% over the untreated control and was the treatment most consistently associated with higher sugar accumulation. Organic matter-based amendments require more than one season to act on such soils, most probably because their mineralisation is limited by the absence of summer rainfall. For organic viticulture on calcareous soils in the region, bacterial biofertilizers offer a candidate route to improved must quality within the first season, while the site-wide zinc deficiency identified here calls for a separate corrective strategy using dilute foliar sprays of ZnSO₄ or Zn-EDTA.

Declarations

Competing interests

The authors declare that they have no competing interests.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

Funding

This work was supported by the Dicle University Scientific Research Projects Coordination Office as a Master's thesis project (Project No. ZİRAAT.21.013).

Author Contribution

GÖ conceived and designed the experiment and supervised the study. BK conducted the field applications, carried out the measurements, and analysed the data. BK and GÖ interpreted the results and wrote the manuscript. Both authors read and approved the final version.

Acknowledgement

The authors thank the grower Ramazan Akçakaya for making the vineyard available and for assistance during the field applications, and Prof.Dr. Metin Turan and Dr. Mustafa Atilla Yazıcı for their help with the plant nutrient analyses. This article is derived from the M.Sc. thesis of the first author, completed at the Institute of Natural and Applied Sciences, Dicle University. The authors also thank the Dicle University Scientific Research Projects Coordination Office for financially supporting this work (Project No. ZİRAAT.21.013).

Data availability

The datasets generated or analysed during the current study are available from the corresponding author on reasonable request.

References

1. Abd Rahman SSN, Tawie Tingga RC, Mohamad Bukhori MF, Ahmad S (2023) A brief review of the nutritive value and chemical components of bat guano and its potential use as a natural fertiliser in agriculture. *Malays Appl Biol* 52:15–26
2. Aguilera P, Ortiz N, Becerra N, Turrini A, Gaínza-Cortés F, Silva-Flores P, Aguilar-Paredes A, Romero JK, Jorquera-Fontena E, Borie F (2022) Application of arbuscular mycorrhizal fungi in vineyards: water and biotic stress under a climate change scenario. *Front Microbiol* 13:826571. <https://doi.org/10.3389/fmicb.2022.826571>
3. Alori ET, Glick BR, Babalola OO (2017) Microbial phosphorus solubilization and its potential for use in sustainable agriculture. *Front Microbiol* 8:971. <https://doi.org/10.3389/fmicb.2017.00971>
4. Ateş F, Uysal H (2017) Determinations of adaptation level of wine grape varieties in terms of climatic data in wine growing regions of Turkey. *J Tekirdağ Agric Fac* 14:187–198

5. Badalíková B, Burg P, Mašán V, Prudil J, Jobbágy J, Čížková A, Krištof K, Vašinka M (2022) Deep placement of compost into vineyard soil affecting physical properties of soils, yield and quality of grapes. *Sustainability* 14:7823
6. Baraza E, Hmida I, Borràs J, Pérez A, Muñoz V, Moyano A (2024) Failures count too: effect of the application of commercial inoculum of arbuscular fungi in a vineyard during its plantation. *J Plant Nutr* 47:2369–2385
7. Biagi M et al (2025) Waste-derived organic soil amendments for a sustainable vineyard management: linking microbiome responses to soil biochemistry. *Appl Soil Ecol* 215:106406
8. Blouin M, Barrere J, Meyer N, Lartigue S, Barot S, Mathieu J (2019) Vermicompost significantly affects plant growth. A meta-analysis. *Agron Sustain Dev* 39:34
9. Candar S, Uysal T, Ayaz A, Yıldırım ZU (2021) Viticulture tradition in Turkey. *MAS J Appl Sci* 6:765–780
10. Christensen P, Jensen F (1978) Grapevine response to concentrate and to dilute application of two zinc compounds. *Am J Enol Vitic* 29:159–162
11. Daccak D, Lidon FC, Marques AC, Pessoa CC, Luís IC, Pinto MG, Simões MM, da Silva JM, Pardo AE, Guerra JCM (2022) Enrichment of grapes with zinc: efficiency of foliar fertilization with ZnSO₄ and ZnO and implications on winemaking. *Plants* 11:2692
12. Daccak D, Marques AC, Pessoa CC, Coelho RF, Lidon FC, Pardo AE, Guerra JCM, da Silva JM, Pinto MG, Simões MM (2024) Foliar spraying with ZnSO₄ or ZnO of *Vitis vinifera* cv. Syrah increases the synthesis of photoassimilates and favours winemaking. *Horticulturae* 10:825
13. Dimande P, Arrobas M, Rodrigues MÂ (2023) Under a tropical climate and in sandy soils, bat guano mineralises very quickly, behaving more like a mineral fertiliser than a conventional farmyard manure. *Plants* 12:3594
14. Döring J, Frisch M, Tittmann S, Stoll J, Kauer M, Wohlfahrt M, Töpfer R (2015) Growth, yield and fruit quality of grapevines under organic and biodynamic management. *PLoS ONE* 10:e0138445
15. Döring J, Frisch M, Tittmann S, Stoll J, Kauer M, Wohlfahrt M, Töpfer R (2019) Organic and biodynamic viticulture affect biodiversity and properties of vine and wine: a systematic quantitative review. *Org Agric* 9:189–203
16. Döring J, Steng K, Wohlfahrt Y, Collins M, Frisch M, Töpfer R (2026) Overcoming yield gaps in organic and biodynamic viticulture: insights from an 18-year field trial. *Agron Sustain Dev* 46:6. <https://doi.org/10.1007/s13593-025-01079-2>
17. Fredeen AL, Rao IM, Terry N (1989) Influence of phosphorus nutrition on growth and carbon partitioning in *Glycine max*. *Plant Physiol* 89:225–230
18. Gaiotti F, Marcuzzo P, Belfiore N, Lovat L, Fornasier F, Tomasi D (2017) Influence of compost addition on soil properties, root growth and vine performances of *Vitis vinifera* cv. Cabernet Sauvignon. *Sci Hortic* 225:88–95
19. Ganugi P, Caffi T, Gabrielli M, Secomandi E, Fiorini A, Zhang L, Bellotti G, Puglisi E, Fittipaldi MB, Asinari F, Tabaglio V, Trevisan M, Lucini L (2023) A 3-year application of different mycorrhiza-based

- plant biostimulants distinctively modulates photosynthetic performance, leaf metabolism, and fruit quality in grapes (*Vitis vinifera* L.). *Front Plant Sci* 14:1237598
20. Jamal A, Saeed MF, Mihoub A, Hopkins BG, Ahmad I, Naeem A (2023) Integrated use of phosphorus fertilizer and farmyard manure improves wheat productivity by improving soil quality and P availability in calcareous soil under subhumid conditions. *Front Plant Sci* 14:1034421
 21. Karaca U, Sabir A (2017) Sustainable mitigation of alkaline stress in grapevine rootstocks (*Vitis* spp.) by plant growth-promoting rhizobacteria. *Erwerbs-Obstbau* 60:211–220. <https://doi.org/10.1007/s10341-017-0361-7>
 22. Lu H, Wu Z, Wang W, Xu X, Liu X (2020) Rs-198 liquid biofertilizers affect microbial community diversity and enzyme activities and promote *Vitis vinifera* L. growth. *Biomed Res Int* 2020:8321462. <https://doi.org/10.1155/2020/8321462>
 23. Lu L, Delrot S, Liang Z (2024) From acidity to sweetness: a comprehensive review of carbon accumulation in grape berries. *Mol Hortic* 4:22
 24. Maia C, Pereira S, Moura R, Brito C, Baltazar M, Martins S, Branco Z, Roboredo M, Nascimento-Gonçalves E, Sousa JR, Coimbra AM, Azevedo T, Lopes H, Morais MC, Oliveira PA, Dinis LT (2026) Modulation of grapevine physiological performance by compost and vermicompost obtained from vine pruning residues. *Plants* 15:558. <https://doi.org/10.3390/plants15040558>
 25. Mairata A, Labarga D, Puelles M, de la Torre JM, Minguéz-Mosquera E, Borde J, Moyano A (2024) Impact of organic mulches on grapevine health, growth and grape composition in nutrient-poor vineyard soils. *OENO One* 58:8265
 26. Marschner P (2012) Mineral nutrition of higher plants, 3rd edn. Academic Press, San Diego
 27. Martínez-Lüscher J, Kurtural SK (2021) Same season and carry-over effects of source-sink adjustments on grapevine yields and non-structural carbohydrates. *Front Plant Sci* 12:695319
 28. Marwa E, Andrew T, Hatibu AA (2021) Challenges facing effective use of bat guano as organic fertilizer in crop production: a review. *Int J Agric Res Innov Technol* 11:35–46
 29. Mohebbi H, Ebadi AA, Hassanzadeh Taheri MM, Naderi M (2022) The effect of different levels of foliar application of zinc, iron, and manganese micronutrients on reproductive characteristics and yield of *Vitis vinifera* grapes in some vineyards of Zanzan Province. *J Hortic Sci* 35:481–495
 30. Morlat R (2008) Long-term additions of organic amendments in a Loire Valley vineyard on a calcareous sandy soil. II. Effects on root system, growth, grape yield, and foliar nutrient status of a Cabernet franc vine. *Am J Enol Vitic* 59:364–377
 31. Morlat R, Chaussod R (2008) Long-term additions of organic amendments in a Loire Valley vineyard. I. Effects on properties of a calcareous sandy soil. *Am J Enol Vitic* 59:353–363
 32. Naseer M, Muhammad D (2014) Direct and residual effect of Hazara rock phosphate on wheat and succeeding maize in alkaline calcareous soils. *Pak J Bot* 46:1755–1761
 33. Nicolás E, Maestre-Valero JF, Alarcón JJ, Fernández MF, Molina JH (2014) Effectiveness and persistence of arbuscular mycorrhizal fungi on the physiology, nutrient uptake and yield of Crimson seedless grapevine. *J Arid Environ* 113:31–38

34. Pellegrino A, Clingeleffer PR, Cooley N, Walker R (2014) Management practices impact vine carbohydrate status to a greater extent than vine productivity. *Front Plant Sci* 5:283
35. Peng YY, Liu CY, Hao Y (2025) Differential effects of arbuscular mycorrhizal fungi on rooting and physiology of 'Summer Black' grape cuttings. *Horticulturae* 11:825. <https://doi.org/10.3390/horticulturae11070825>
36. Schneider N, Islam MS, Wehrle R, Pätzold S, Brüggemann N, Töpfer R, Herzog K (2023) Deep incorporation of organic amendments into soils of a 'Calardis Musqué' vineyard: effects on greenhouse gas emissions, vine vigor, and grape quality. *Front Plant Sci* 14:1252560
37. Sridhar KR, Ashwini KM, Seena S, Kannada D (2006) Manure qualities of guano of insectivorous cave bat *Hipposideros speoris*. *Curr Sci* 90:246–249
38. Torres N, Antolín MC, Goicoechea N (2018) Arbuscular mycorrhizal symbiosis as a promising resource for improving berry quality in grapevines under changing environments. *Front Plant Sci* 9:897. <https://doi.org/10.3389/fpls.2018.00897>
39. Vasconcelos MC, Greven M, Winefield CS, Trought MCT, Raw V (2009) The flowering process of *Vitis vinifera*: a review. *Am J Enol Vitic* 60:411–434
40. Zhang X, Wang X, Wang X, Xia G, Wu Q, Xiang L (2006) A shift of phloem unloading from symplasmic to apoplasmic pathway is involved in developmental onset of ripening in grape berry. *Plant Physiol* 141:305–318
41. Zhao A, Tian X, Cao Y, Lu X, Liu T (2014) Comparison of soil and foliar zinc application for enhancing grain zinc content of wheat when grown on potentially zinc-deficient calcareous soils. *J Sci Food Agric* 94:2016–2022