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Research Article

Impact of Fertilizer Application Methods on the Productivity and Quality of the 'Bordô' Grape Cultivar

Impacto do modo de aplicação de fertilizantes na produtividade e qualidade de videira cultivar 'Bordô'

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ABSTRACT

The search for alternatives to improve technical efficiency and profitability in grape cultivation has driven the adoption of new water and nutrient management strategies. In this context, this work aimed to evaluate the effects of different forms of soluble fertilizer application, via soil and via water, on the productivity and quality of 'Bordô' grape cultivars. The research was carried out on a property located in Travessão Divisa, in the interior of the municipality of Nova Pádua, RS, in a vineyard established 16 years ago. The experiment was conducted in plots due to the treatments' specificity, with three treatments and 15 repetitions. The treatments consisted of a control (T1) without fertilization, fertilization with soluble sources applied to the soil (T2), and fertilization with soluble sources applied via water (T3). The fertilizer doses followed the producer's standard, namely 65.5 kg·ha^{-1} of N, 65 kg·ha^{-1} of K_2O, 7.4 kg·ha^{-1} of S, 57 kg·ha^{-1} of Ca, and 6 kg·ha^{-1} of Mg. Fertilizer application was equal in treatments T2 and T3; however, in T2, fertilizers were applied in a single dose. During the experiment, chlorophyll and foliar nutrient levels were evaluated, and at the end, crop productivity, production parameters, and bunch quality were assessed. The results demonstrated that fertilization with soluble sources added via soil or irrigation water favored the absorption of Ca and P, and reduced the absorption of B. Application via irrigation water favored N absorption, while application via soil favored K absorption; the treatments did not influence the absorption of other nutrients. Both fertilization methods increased the productivity of the 'Bordô' grapevine and improved most of the fruit quality parameters evaluated. However, the application of fertilizers via water was superior in the parameters number of bunches, bunch and berry diameter, and must pH. Thus, the application of soluble fertilizers via soil and via water is an effective strategy for the nutritional management of the crop under the edaphoclimatic conditions of the experiment. However, the application of split fertilization via water stands out in relation to application via soil, indicating its potential as an agronomic practice for increasing the productivity and quality of the 'Bordô' grapevine.

KEYWORDS: Soil fertilization. Fertilization via water. Soluble nutrient sources. Fertigation.

RESUMO

A busca por alternativas que promovam maior eficiência técnica e rentabilidade no cultivo da videira tem impulsionado a adoção de novas estratégias de manejo hídrico e nutricional. Nesse contexto, este trabalho teve como objetivo avaliar os efeitos de diferentes formas de aplicação de fertilizantes solúveis, via solo e via água, sobre a produtividade e a qualidade das uvas da cultivar 'Bordô'. A pesquisa foi realizada em uma propriedade localizada no Travessão Divisa, interior do município de Nova Pádua - RS, em um vinhedo implantado há 16 anos. O experimento foi conduzido em pacelões devido a especificidade dos tratamentos, com três tratamentos e 15 repetições. Os tratamentos consistiram em testemunha (T1) Sem Adubação, Adubação com Fontes Solúveis via Solo (T2) e Adubação com Fontes Solúveis via Água (T3). As doses e fertilizantes seguiu o padrão utilizado pelo produtor sendo: 65,5 kg·ha^{-1} de N, 65 kg·ha^{-1} de K_2O, 7,4 kg·ha^{-1} de S, 57 kg·ha^{-1} de Ca e 6 kg·ha^{-1} de Mg A aplicação dos fertilizantes ocorreu de forma igualitária nos tratamentos T2 e T3; entretanto, no T2, os fertilizantes foram aplicados em dose única. Durante a condução do experimento, foram avaliados os teores de clorofila e de nutrientes foliares e, ao término, a produtividade

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da cultura, bem como os parâmetros de produção e de qualidade dos cachos. Os resultados demonstraram que a adubação com fontes solúveis adicionadas tanto via solo como via água favoreceu a absorção dos nutrientes Ca e P e reduziu a absorção de B. A aplicação dos adubos via água de irrigação favoreceu a absorção de N enquanto a aplicação via solo favoreceu a absorção de K, sendo que a absorção dos demais nutrientes não foi influenciada pelos tratamentos. Ambas as formas de adubação aumentaram a produtividade da videira cv. Bordô e melhoraram a maioria dos parâmetros de qualidade dos frutos avaliados. Contudo, a aplicação de fertilizantes via água foi superior nos parâmetros número de cachos, diâmetro dos cachos e das bagas e pH do mosto. Assim, as aplicações de fertilizantes solúveis via solo e via água configuram-se como estratégias eficazes para o manejo nutricional da cultura nas condições edafoclimáticas do experimento. No entanto, a aplicação da adubação parcelada via água destaca-se em relação a aplicação via solo, indicando seu potencial como prática agronômica para o aumento da produtividade e da qualidade da videira 'Bordô.
PALAVRAS-CHAVE: Adubação via solo. Adubação via água. Fontes solúveis de nutrientes. Fertirrigação.

INTRODUCTION

Brazil ranks 13th in world grape production, with China leading the rankings at 12.6 million tons in 2022 (FAO 2022). The average production yield in the country is around 23 $t \cdot ha^{-1}$ (IBGE 2023). In the Southern region, the viticultural area accounted for 73% of the total national production area (MELLO & MACHADO 2022).

Nutritional management is one of the practices that most favor the productivity and quality of grapes, as it ensures that the plant receives the nutrients it needs for its development. Nutrient applications should be carried out according to the appropriate quantity and the needs of each location and variety (TECCHIO et al. 2021). Conventional fertilization relies on applying fertilizers to the soil and on rainfall or irrigation for the nutrients to dissolve and be absorbed. In fertigation, nutrients are already diluted in water, allowing uniform distribution in the root zone and rapid root absorption. Among the benefits of this technique are reduced labor demand and reduced traffic of people or machines, thereby avoiding soil compaction (COELHO et al. 2022). In vineyards, especially in semi-arid regions, fertigation allows fractionation of nutrient application throughout the phenological cycle, better aligning nutrient supply with plant demand (ALBUQUERQUE et al. 2013).

Drip fertigation systems increase productivity by 10 – 15 % and significantly improve water-use efficiency, while also increasing fertilizer use efficiency compared to conventional application, reducing fertilizer use by 25 % without substantially decreasing productivity. In general, fertigation can be recommended as an effective practice; however, the results obtained vary under different conditions, and there are discrepancies in the findings. Nevertheless, fertigation at certain fertilizer levels can have adverse effects on crops (DELBAZ et al. 2023). Fertilizers are salts that increase the saline concentration of irrigation water; improper use can lead to soil salinization and salinity problems in plants. (SILVA & SOARES 2009).

Experimental results for the proper management of fertigation in grapevines in southern Brazil are, unfortunately, still incipient, as are the impacts of the technique on the quality of the harvested product (PALARETTI & ROZANE 2025, BRUNETTO et al. 2025). Thus, although fertigation can offer substantial advantages in terms of productivity and plant nutrition, its success depends on fine-tuning of doses,

application frequency, and adequate monitoring, especially in regions vulnerable to leaching or salinization (DELBAZ et al. 2023).

Much of the production system for 'Bordô' grapevines in the Serra region of Rio Grande do Sul uses traditional sources of fertilizer (urea, triple superphosphate, and potassium chloride, and/or organic fertilizers) in more rustic cultivation systems. However, the search for alternatives that improve technical efficiency and profitability in cultivation has driven the adoption of new water and nutrient management strategies. Extrapolating recommendations used in the fertigation of other cultivars to the Bordô cultivar requires caution, given its distinct physiology, nutritional requirements, and cultivation system. Therefore, studies are needed to clarify the efficiency of different fertilization methods in this cultivar, to support practical recommendations applicable to producer management, and to promote the social, economic, and environmental sustainability of production systems.

Therefore, this work aimed to evaluate the effects of different methods of applying soluble fertilizers, via soil and via water, on the quality of grapes and the productivity of the 'Bordô' cultivar.

MATERIAL AND METHODS

The experiment was conducted on a rural property in the municipality of Nova Pádua, in the state of Rio Grande do Sul, at the geographical coordinates of 29°01'S 51°16'W and an altitude of 674 m, with a subtropical Cfb climate (ALVARES et al. 2013) and the predominant soil type being Cambisol (STRECK et al. 2018). The soil fertility conditions before the experiment was set up, as well as their interpretation, are compiled in Table 1.

The vineyard was established 16 years ago with a spacing of 2.5 m x 2.0 m, using the Ives cultivar grafted onto Paulsen 1103 rootstock, in a pergola training system.

Table 1. Soil characterization in the 0-20 cm layer, performed in June 2024, post-harvest, before the implementation of the experiment. Nova Pádua – RS, 2025.

Parameter	Unit	Result	Interpretation	Reference
pH	-	5.7	Medium acidity	1
H+Al	$cmol_c \cdot dm^{-3}$	5.3	High	1
Clay	% w/v	39	Class 3	2
CEC $_{pH\ 7.0}$	$cmol_c \cdot dm^{-3}$	16.2	High	2
OM	% w/v	2.1	Low	2
Al	$cmol_c \cdot dm^{-3}$	0.11	Low	1
Ca	$cmol_c \cdot dm^{-3}$	8	High	2
Mg	$cmol_c \cdot dm^{-3}$	2.5	High	2
K	$mg \cdot dm^{-3}$	164	High	2
P	$mg \cdot dm^{-3}$	22.2	High	2
S	$mg \cdot dm^{-3}$	14.1	High	2
Zn	$mg \cdot dm^{-3}$	16	High	2
Cu	$mg \cdot dm^{-3}$	4.5	High	2
Mn	$mg \cdot dm^{-3}$	14.5	High	2
B	$mg \cdot dm^{-3}$	1.1	High	2

1 - PREZOTTI & GUARÇONI (2013); 2 - CQFS - RS/SC (2016).

The experiment was conducted in plots due to the treatments' specificity, consisting of three treatments with three rows of the crop, divided into 15 repetitions (five repetitions of two plants per row), i.e., 30 plants per treatment. For the study, the following treatments were used: no fertilization (T1), soil fertilization (T2), and water fertilization (T3), in an area of 1,470 m² within the vineyard.

The fertilizers used were in accordance with those adopted by the producer throughout the vineyard: for T2 and T3, Calcinit, Krista K, and Magnesium Ultra were used; for the control, only irrigation was applied, as per Table 2. The fertilizers used in the treatments were composed of: YaraTera™ Calcinit Nitrogen (N) 15.5 % w/w, of which Nitric N 14.4 % w/w, Ammoniacal N 1.1 % w/w, Calcium (Ca) 19 % w/w; YaraTera Krista K Nitrogen (N) 13 % w/w, Potassium Oxide (K_2O) 43 % w/w, Magnesium (Mg) 1 % w/w, Sulfur (S) 1 % w/w; Magnesium Ultra Magnesium (Mg) 9 % w/w, Sulfur (S) 11.8 % w/w, Potassium (K) 1 % w/w. The doses used also followed those adopted by the producer: 65.5 kg·ha^{-1} of N, 65 kg·ha^{-1} of K_2O, 7.4 kg·ha^{-1} of S, 57 kg·ha^{-1} of Ca, and 6 kg·ha^{-1} of Mg. It should be noted that all fertilizers used for water-based fertilization (T3) were also used for soil-based fertilization (T2), but applied only once.

Table 2. Timing of soluble fertilizer application in the different treatments during the phenological development of the grapevine. Nova Pádua, RS, 2025.

Treatments	Phase	Calcinit®	Krista K®	Mg Ultra®
No fertilization (T1)	-	-	-	-
Soil fertilization (T2)	Beginning of budding to the beginning of flowering	1 application of 200 kg·ha^{-1}	-	-
	Chumbinho at the beginning of bunch compaction	1 application of 100 kg·ha^{-1}	1 application of 150 kg·ha^{-1}	1 application of 50 kg·ha^{-1}
Water fertilization (T3)	Beginning of budding to the beginning of flowering	4 applications of 50 kg·ha^{-1}	-	-
	Chumbinho at the beginning of bunch compaction	2 applications of 50 kg·ha^{-1}	3 applications of 50 kg·ha^{-1}	2 applications of 25 kg·ha^{-1}

In the treatment with soluble fertilizers applied via water (T3), fertilization was carried out as follows: from the beginning of sprouting until the start of flowering, 200 kg·ha^{-1} of calcium nitrate (commercial product Calcinit) was applied, totaling 30 kg of N, divided into four applications. During the small grain stage (grain size) until the beginning of cluster compaction, 150 kg·ha^{-1} of potassium nitrate (Krista K) was applied in three applications, providing 18 kg of N and 67.5 kg of K_2O. In addition, another 100 kg·ha^{-1} of calcium nitrate (Calcinit) was applied in two applications, providing 15 kg of N. Furthermore, 50 kg·ha^{-1} of magnesium sulfate was applied in two applications of the Magnesium Ultra fertilizer, providing 45 kg of Mg, carried out at separate times from the Calcinit applications to avoid incompatibility.

In soil fertilization (T2), the same fertilizers and doses used in fertigation were applied all at once, distributed evenly across the soil surface. At the same time, the drip irrigation system remained in place. Calcinit was used at the beginning of

September 2024, while Krista K and Magnesium Ultra were applied at the beginning of November 2024. For the control, only irrigation was maintained (T1), with no fertilizer applied.

Irrigation was carried out weekly and twice a week during periods without rainfall. The volume of water used per irrigation was 16,000 $L \cdot ha^{-1}$, and each irrigation lasted 1 h across all treatments, as indicated in Table 2 for fertigation. Only in the treatment with fertilization via water were fertilizers added to the remaining volume of water (i.e., 8,000 $L \cdot ha^{-1}$) from 30 min onwards.

The pruning period for the crop was from the second half of July until the beginning of September 2024. The type of pruning adopted was mixed, alternating canes and spurs on the same branch of the plant. Chemical control with fungicides, herbicides, and insecticides was carried out as needed throughout the cycle.

This experiment evaluated the nutrient and chlorophyll content in the leaves, crop productivity, number of bunches per plant, bunch weight, length and diameter, number of berries per bunch, berry weight and diameter, and qualitative aspects of the grapes (soluble solids content, titratable acidity, pH, phenolic compounds, flavonoids, and anthocyanins).

To determine the nutrient content in grapevine leaves, a foliar analysis was performed with three replicates per treatment, considering each row as a replicate. In each replicate, complete leaves (blade + petiole) were collected from fifteen plants at the berry color change stage. The samples were dried in a forced-air oven at an average temperature of 65 ºC, ground, and analyzed for total macro and micronutrient content according to the methods described by MALAVOLTA et al. (1997).

Chlorophyll A, B, and total levels in the leaves were evaluated using a Falker Clorofilog® chlorophyll meter on three fully developed leaves from each replicate, totaling 15 leaves per row and 45 leaves per treatment, at two time points: flowering and berry color change.

During the physiological maturation phase of the grapes, two plants per replicate were evaluated, totaling 30 per treatment, to assess the crop's yield components. All bunches from the plants were counted to determine the number of bunches per plant, weighed to determine productivity, and the average bunch mass. Additionally, two bunches per replicate were collected to assess bunch length and diameter, for a total of 30 bunches per treatment. For the analysis of berry characteristics, two bunches from each replicate were selected, and twenty random berries from each bunch were measured using a caliper to obtain the berry diameter values, in centimeters.

For the evaluation of the qualitative parameters of titratable acidity, soluble solids content, and pH, five replicates per treatment were adopted. One hundred and fifty berries per treatment were collected at physiological maturity. In each replicate, six bunches were selected, with a total of five berries from each bunch being used, totaling thirty berries in one replicate. The berries were frozen for five weeks and thawed on the day of the evaluation of soluble solids, titratable acidity, pH, and phenolic compounds, flavonoids, and anthocyanins.

The soluble solids (SS) content was determined using an Atago RX-5000cx digital refractometer, with results expressed in degrees Brix (°Bx). Titratable acidity was determined by neutralization titrimetry, with results expressed in grams of tartaric

acid per 100 g of sample. A digital pH meter (DM-22, Digimed®, Brazil) was used to determine the pH. The ratio between soluble solids and titratable acidity was also determined by the quotient between these two parameters. The analyses followed the methods described by ZENEBON & PASCUET (2005).

To determine the levels of phenolic compounds, flavonoids, and anthocyanins in grapes, extraction was performed using a hydroalcoholic solution. The extracts were prepared by mixing 10 g of homogenized sample with 50 mL of 70 % v/v ethanol, and the mixture was left to stand for 12 h at room temperature (20 – 25 °C).

The total phenolic content was determined by the Folin-Ciocalteu method, as described by PEREIRA et al. (2018). The results were expressed in milligrams of gallic acid equivalents (GAE) per 100 g of sample. The flavonoid content was determined by the aluminum chloride spectrophotometric method, as described by MATIC et al. (2017), and the results were expressed in milligrams of quercetin equivalent per 100 g of fruit. The anthocyanin content was determined by the differential pH method, according to AOAC 2005.02, proposed by LEE et al. (2005), and the results were expressed in milligrams of cyanidin-3-glucoside equivalent per 100 g of fruit.

The data obtained were analyzed for homoscedasticity using Levene's test and for normality using the Shapiro-Wilk test (SPSS 21.0). Mean comparisons were performed using analysis of variance (ANOVA), followed by Tukey's test ($p \leq 0.05$), using AgroEstat software version 1.1.0.712.

RESULTS AND DISCUSSION

The results of the leaf analysis performed at the berry color change stage showed significant differences in nitrogen (N), calcium (Ca), phosphorus (P), and potassium (K) levels. At the same time, the other macronutrients did not differ between treatments (Table 3).

Table 3. Macronutrients present in the leaves of the Bordô grapevine cultivar and their influence on berry color change under different fertilization methods. Nova Pádua – RS, 2025.

Treatments	N	Ca	Mg	P	K	S
	g·kg^{-1}					
No fertilization (T1)	31.5 ab	11.8 b	2.2 ^{ns}	2.3 b	9.1 b	2.5 ^{ns}
Soil fertilization (T2)	31.1 b	16.2 a	2.3	2.7 a	10.8 a	2.7
Water fertilization (T3)	31.9 a	16.2 a	1.9	2.7 a	10.1 ab	2.7
CV (%)	0.71	8.92	7.46	2.87	4.97	11.0

Means followed by different letters in the column differ from each other by Tukey's test ($p < 0.05$). ^{ns}: not significant by the F test ($p < 0.05$). CV: coefficient of variation.

It is noteworthy that nitrogen (N) levels were excessive in all treatments. Calcium (Ca) was at adequate levels in fertigation and conventional systems**,** but insufficient for control. Magnesium (Mg) was insufficient in the treatment with water fertilization, whereas it was normal in the control and in the soil fertilization treatment. The levels of phosphorus (P), potassium (K), and sulfur (S) remained within the normal range across all treatments (CQFS - RS/SC 2016).

The nitrogen content in soil fertilization was statistically lower than that of water fertilization, possibly due to the single application of nitrogen fertilizer, which may have favored losses through leaching. Nitrate leaching can compromise nitrogen uptake

efficiency in plants. The application of high nitrogen fertilizer doses favors nitrate leaching (FREITAS 2021). According to MOTA et al. (2015), N use efficiency decreased with increasing N doses in topdressing. ZANIN et al. (2022) also suggest that fractionation can lead to beneficial effects on the grapevine in the long term. On the other hand, mineral sources with a more gradual nutrient release are constantly being developed by the market (BRUNETTO et al. 2025). Thus, the results obtained in this work indicate the need to split nitrogen fertilization or to use other sources, especially when applied to the soil, to reduce leaching and environmental contamination.

Leaf Ca levels were higher in treatments with soil fertilization (T2) and water (T1) than in those without fertilization, due to application via Calcinit fertilizer. Calcium is an essential element for grape growth and development, improving fruit quality and promoting productivity (YUE et al. 2025). However, according to NACHTIGALL (2012), to obtain productive plants with high nutritional quality, it is essential to ensure balanced availability and absorption, as an imbalance in this equilibrium can result in nutritional deficiencies.

The concentration of Mg in grapevine leaves did not vary between treatments, possibly because of its high mobility in the plant and its availability in the soil, where this nutrient showed high values (Table 1). However, in the treatment with fertilization via water, insufficiency was observed, possibly because of the absorption of Ca and K. According to COPP (2025), high concentrations of potassium and calcium in the soil can reduce the absorption of Mg, which can induce a deficiency of this mineral in grapevines, even with high levels of Mg in the soil.

Although the applied fertilizers did not contain phosphorus, there was greater absorption of this nutrient in response to the supply of other elements. According to YAO et al. (2024), phosphate ions Ca and Mg can have a synergistic effect on P accumulation in plants, and vice versa, with this effect being associated with the ionic balance linked to the absorption of cations and anions by plants. Thus, the application of Ca and Mg can increase P levels. In addition, according to GAO et al. (2024), increased N deposition intensifies the mineralization of organic P by stimulating phosphatase and microbial activity in the soil, thereby increasing P availability, meeting plant needs, and mitigating P limitation. PASLEY et al. (2019) also observed that N application increased phosphorus (P) absorption in maize.

K fertilization resulted in a significant increase in soil K levels. However, water fertilization did not differ statistically from the other treatments. This performance may be related to its higher concentration at the drip points, which can increase K saturation in the CEC, facilitating its leaching (RIBEIRO et al. 2022, NIGON et al. 2025).

The absence of significant differences in foliar sulfur (S) content between treatments indicates that the natural soil supply, combined with the contribution of organic matter, was sufficient to maintain adequate levels of this nutrient in the plants, regardless of the method of fertilizer application (soil or water). Furthermore, it is noteworthy that sulfur applied for phytosanitary purposes, especially in the control of powdery mildew, can also be absorbed via the leaves, contributing to the nutritional status of the grapevine (GLUHIĆ 2022).

The analysis of foliar micronutrients, described in Table 4, showed differences between treatments only for boron (B), with the control showing higher values than the other treatments. However, zinc (Zn) levels were insufficient in all treatments; boron (B) levels were adequate only in the control and insufficient in treatments with soil and water fertilization; manganese (Mn) levels were adequate in all treatments; and iron (Fe) levels were sufficient in water fertilization and excessive in the other treatments (CQFS-RS/SC 2016).

Table 4. Micronutrients present in the leaves of the Bordô grapevine cultivar and their effect on berry color change under different fertilization methods. Nova Pádua – RS, 2025.

Treatments	Zn	Cu	B	Mn	Fe
	mg·kg $^{-1}$				
No fertilization (T1)	23.4 ^{ns}	6.1 ^{ns}	31.0 a	111.4 ^{ns}	164.3 ^{ns}
Soil fertilization (T2)	24.5	7.0	27.8 b	142.9	177.8
Water fertilization (T3)	24.1	6.7	24.3 c	151.9	143.5
CV (%)	13.04	11.96	3.23	21.93	22.50

Means followed by different letters in the column differ from each other by Tukey's test ($p < 0.05$). ^{ns}: not significant by the F test ($p < 0.05$). CV: coefficient of variation.

According to CQFS (2016), Zn and Cu levels were high in the soil analysis conducted in 2024 for the experiment. The excess of Zn and Cu may be related to the chemical characteristics of the region's soils, which are usually high, potentially causing plant toxicity. Furthermore, the high levels of calcium (8.0 $cmol_c \cdot dm^{-3}$) and P (22.2 $mg \cdot dm^{-3}$) found in the soil analysis may compete with zinc, reducing its absorption. In plants, Zn interacts negatively with these nutrients (ROZANE et al. 2020), which may explain the low foliar levels, even in soil with high Zn levels.

Regarding copper, the Fertilization and Liming Manual for the states of Rio Grande do Sul and Santa Catarina does not provide an interpretation of Cu content in grapevine leaves; in this study, the normal ranges for *Vitis vinifera* were used, following the CND method (10 – 14 $mg \cdot kg^{-1}$) described in ROZANE et al. (2020) to evaluate this micronutrient, which was found to be below the normal range.

The B content in the soil, according to the analysis carried out in May 2024, was high (Table 1). However, in the foliar analysis, the treatments with soil and water applications showed insufficient boron levels. According to SARKIS et al. (2024), B is readily leached from soil, and its availability to plants can be restricted by soil texture and organic matter content, which directly influence its retention and absorption. Studies indicate that high nitrogen levels can reduce boron absorption in plants, highlighting an antagonistic relationship between these nutrients (KOOHKAN & MAFTOUN 2016). Thus, the increase in nitrogen levels may have reduced plant absorption.

In the evaluation of chlorophyll A, B, and total levels, significant differences were observed between the treatments (Table 5). In phase 1 (flowering), soil fertilization showed the highest values, surpassing the other treatments. In chlorophyll B during this same phase, water fertilization and the control (without fertilization) did not differ from each other. However, in phase 2 (change in berry color), water fertilization showed higher levels of chlorophyll A, B, and total chlorophyll than the control.

Table 5. Index of Chlorophyll A, B, and total chlorophyll in grapevine leaves during the flowering and berry color change stages of the Bordô cultivar under different fertilization methods. Nova Pádua - RS, 2025.

Treatments	Flowering			Change in berry color		
	A	B	Total	A	B	Total
No fertilization (T1)	32.6 c	7.8 b	40.5 c	39.2 b	9.7 b	48.9 b
Soil fertilization (T2)	37.2 a	8.9 a	46.2 a	40.4 ab	10.6b	51.1 b
Water fertilization (T3)	35.1 b	8.1 b	43.5b	42.1 a	11.8 a	53.9 a
CV (%)	8.21	14.66	8.67	9.12	17.4	10.2

Means followed by different letters in the column differ from each other by Tukey's test ($p < 0.05$). CV: coefficient of variation.

Chlorophyll, responsible for photosynthesis, contains magnesium and nitrogen; therefore, these elements are structural components of chlorophyll (ALBERTS et al. 2017). Thus, the observed effects on chlorophyll may be related to the fertilization performed. During the flowering phase, the higher chlorophyll levels in the soil-based fertilization system can be attributed to the concentrated nutrient application, a characteristic of this management practice. It should be noted that the application of Calcinit, a nitrogen source, was carried out in mid-September 2024, and the grapevine flowering occurred in mid-October 2024. As the interval between fertilization and flowering was short (about a month), rainfall and irrigation during this period likely did not cause significant leaching, allowing nitrogen to remain available in sufficient quantity to support chlorophyll synthesis. Unlike water-based fertilization, which provides nutrients in installments, the immediate nitrogen concentration in soil-based fertilization may have contributed to its prominence during the flowering phase.

In the berry color change phase, fertilization via water stood out significantly, possibly due to the installment and continuous supply of nutrients, which ensured greater availability of N and Mg from the Calcinit and Magnesium Ultra fertilizers applied in this treatment, until dates close to the chlorophyll evaluation. In soil fertilization, these nutrients were used as a single dose, with N supplied at the beginning of September 2024 and Mg at the beginning of November 2024, resulting in a longer interval between applications. Although Mg was applied in November, chlorophyll has a central Mg atom and several N atoms around it, with nitrogen being the nutrient with the greatest influence (ALBERTS et al. 2017).

The results obtained regarding productive parameters indicated advantages of fertilization via water over soil fertilization and no fertilization for bunch and berry diameter. However, the other productive parameters evaluated were superior to the control in both water- and soil-applied fertilization (Table 6).

Table 6. Productive parameters of the Bordô cultivar under different fertilization methods. Nova Pádua - RS, 2025.

Treatments	Bunches per plant	bunch mass	Curl length	Bunch diameter	Berry diameter	Production per plant	Productivity
	un.	g	---------- cm ----------			kg	t·ha^{-1}
No fertilization (T1)	193 b	97.2 b	11.1 b	4.31 c	1.44 c	18.7 b	37.4 b
Soil fertilization (T2)	200 ab	102.1 a	12.7 a	5.27 b	1.64 b	20.4 a	40.8 a
Water fertilization (T3)	208 a	102.2 a	13.0 a	5.75 a	1.78 a	21.2 a	42.4 a
CV (%)	11.0	5.19	8.4	12.9	4.84	11.4	11.4

Means followed by different letters in the column differ from each other according to Tukey's test ($p < 0.05$). CV: coefficient of variation.

It is noteworthy that, although fertilization via water showed a significant difference compared to fertilization via soil in terms of bunch and berry diameter, the other productive parameters, including production per plant and productivity, were statistically equal between the different forms of fertilization and superior to the control (without fertilization), indicating that both provided these nutrients in sufficient quantities at these productivity levels. However, the possibility of responses to the application of other elements and/or at different stages of development may still need to be better elucidated.

The experimental period was marked by rainfall below the climatological normal for most months of the experiment, according to records from a nearby station (Bento Gonçalves – RS). The following rainfall amounts were observed: 121.4 mm in September 2024 (normal 161.3 mm), 85.9 mm in October 2024 (normal 185.6 mm), 246.2 mm in December 2024 (normal 128.6 mm), and 83 mm in January 2025 (normal 162.1 mm) (EMBRAPA UVA E VINHO 2025, INMET 2025).

The low rainfall may have favored the effectiveness of soil fertilization. Under higher rainfall, there is a tendency toward greater nutrient leaching (NOVAIS et al. 2007), which can compromise the efficiency of soil fertilization when applications are not split (Table 2). However, according to PEREIRA et al. (2019), fertilization combined with irrigation can yield significant gains for the crop, as fertigation increases nutrient delivery to the roots. It is also noteworthy that the results observed in the control demonstrated the importance of the fertilization carried out, as the lack of essential nutrient supply can limit crop production.

Qualitative analysis of the fruits revealed that fertilization significantly influenced pH, titratable acidity (TA), and the TA/SS ratio. However, it did not alter soluble solids (SS) content, which remained stable across treatments (Table 7).

Table 7. Qualitative parameters of the Bordô cultivar under different fertilization methods. Nova Pádua – RS, 2025.

Treatments	pH	Soluble solids	Titratable Acidity	SS/TA Ratio
		ºBx	% w/v	
No fertilization (T1)	2.93 c	13.7 ^{ns}	1.26 a	10.87 b
Soil fertilization (T2)	3.17 a	14.1	1.04 b	13.56 a
Water fertilization (T3)	3.08 b	14.2	1.01 b	14.06 a
CV (%)	1.81	5.40	10.72	10.85

Means followed by different letters in the column differ from each other by Tukey's test ($p < 0.05$). ^{ns}: not significant by the F test ($p < 0.05$). CV: coefficient of variation.

Fertilization, both via soil and water, reduced fruit acidity and increased pH, possibly due to a greater supply of nutrients, such as potassium, which influences the metabolism of organic acids in plant tissues. A study by WANG et al. (2024) shows that potassium fertilizers (such as potassium sulfate) increased potassium content in fruits, reduced the content of organic acids (such as tartaric and malic), and positively influenced fruit pH.

According to Brazilian legislation, Normative Instruction No. 14, of February 8, 2018, from the Ministry of Agriculture and Livestock, the minimum content of soluble solids for grape juices, expressed in Brix degrees (°Bx) at 20 °C, is 14.0 (MAPA 2018), therefore, the treatments that received fertilization met this requirement, which

reinforces the importance of fertilization for the quality of the final product. Regarding the SS/TA ratio, which expresses the balance between total soluble solids and titratable acidity, the highest values were observed in the fertilization treatment, whether via water or soil, indicating a higher quality for juice production (CHIAROTTI et al. 2011). Furthermore, the authors highlight the ratio of total soluble solids to titratable acidity as a reliable indicator of the grape's degree of ripeness.

The phenolic compounds and anthocyanins in grape juice were not influenced by the different treatments (Table 8). Regarding flavonoids, however, variation was observed between the control and the other treatments, with the highest concentration in the control.

Table 8. Qualitative parameters of the Bordô cultivar under different fertilization methods. Nova Pádua – RS, 2025.

Treatments	Flavonoids	Phenolic compounds	Anthocyanins
	---------- mg·100 g^{-1}----------		
No fertilization (T1)	30.97 a	37.13 ^{ns}	36.89 ^{ns}
Soil fertilization (T2)	20.85 b	51.92	44.11
Water fertilization (T3)	18.77 b	46.82	55.31
CV (%):	21.04	21.10	27.14

Means followed by different letters in the column differ from each other by Tukey's test ($p < 0.05$). ^{ns}: not significant by the F test ($p < 0.05$). CV: coefficient of variation.

The reduction in flavonoid levels with fertilization may be associated with greater accumulation of these compounds in plants under nitrogen deficiency. According to ZOU et al. (2025), plants under stress due to low nitrogen availability positively regulate flavonoid biosynthesis as an adaptive mechanism to N deficit, suggesting that nutrient limitation may increase the production of these compounds.

It is noteworthy that all treatments received the same volume of water via drip irrigation and that the climatic conditions during the experiment, especially in October and November, were marked by lower rainfall (603.5 mm) than the climatological normal (776 mm) for the same period (EMBRAPA UVA E VINHO 2025, INMET 2025). This water condition must have influenced the utilization of the applied nutrients, contributing to the absence of significant differences between treatments with different forms of soluble fertilizer application, both in productivity and in most qualitative parameters of the fruits. In years with higher rainfall, the greater leaching can compromise the efficiency of soil fertilization, favoring application via irrigation. In addition, soil fertilization is usually carried out in vineyards without irrigation, which affects the availability of nutrients applied at the soil surface. Thus, in years of water deficit, fertilization via irrigation should show superior responses than conventional fertilization without irrigation.

Furthermore, it should be noted that a complete fertigation system with all nutrients, applied in installments throughout the cycle and adapted to the plant phases, still needs to be better studied to define the ideal for the "Bordô" cultivar, which could present greater advantages compared to the conventionally used system (less soluble fertilizers applied to the soil and without irrigation). In this context, expanding long-term studies on fertilization and fertigation strategies is fundamental to establishing a

consistent technical basis that supports producers of the 'Bordô' cultivar in making decisions about adopting these practices.

CONCLUSION

Under the tested conditions, both forms of fertilization increase the productivity of the 'Bordô' grapevine and improve most of the fruit quality parameters evaluated. However, the application of fertilizers via irrigation water is superior in terms of the number of bunches, the diameter of bunches and berries, and the pH of the must. Thus, the application of soluble fertilizers via soil and irrigation water is an effective strategy for the nutritional management of the crop under the edaphoclimatic conditions of the experiment. However, split fertilization via irrigation water stands out compared to soil application, indicating its potential as an agronomic practice to increase the productivity and quality of the 'Bordô' grapevine.

NOTES

AUTHOR CONTRIBUTIONS

Conceptualization, methodology, and formal analysis, Kelly Tatto and Elaine Damiani Conte; investigation, Kelly Tatto; resources and data curation, Wendel Paulo Silvestre and Elaine Damiani Conte; writing-original draft preparation, Kelly Tatto; writing-review and editing, Wendel Paulo Silvestre and Elaine Damiani Conte; visualization, Wendel Paulo Silvestre; supervision, Elaine Damiani Conte. All authors have read and agreed to the published version of the manuscript.

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CONFLICTS OF INTEREST

The authors have no conflicts of interest to disclose.

REFERENCES

ALBERTS B et al. 2017. Fundamentos da biologia celular. 4.ed. [Recurso eletrônico]. Tradução de Andrade AE et al. Porto Alegre: Artmed.

ALBUQUERQUE AHP et al. 2013. Irrigação e fertirrigação potássica na cultura da videira em condições semiáridas. Pesquisa Agropecuária Tropical 43: 315–321.

ALVARES CA et al. 2013. Köppen's climate classification map for Brazil. Meteorol. Zeitschrift 22: 711–728.

BRUNETTO G et al. 2025. Calagem, adubação e estado nutricional em videiras. In: BRUNETTO G et al. Atualização técnica sobre calagem e adubação em frutíreas. Sociedade Brasileira de Ciência do Solo. 544 p.

CHIAROTTI F et al. 2011. Melhoria da qualidade de uva 'Bordô' para produção de vinho e suco de uva. Revista Brasileira de Fruticultura *33*: 618–624.

COELHO E F et al. 2022. Fertirrigação. In: OLIVEIRA AMG & MEISSNER FILHO PE. Eds. Mamoeiro do grupo Solo: cultivo, colheita, pós-colheita e comercialização. Brasília: Embrapa.

COPP CR. 2025. Foliar Magnesium fertiliser remediates induced Mg deficiency in cation-rich vineyard soils. OENO On 59: 3.

CQFS – RS/SC. 2016. Comissão de Química e Fertilidade do Solo. Manual de calagem e adubação para os Estados de Rio Grande do Sul e de Santa Catarina. Viçosa: SBCS. 376p.

DELBAZ R et al. 2023. A global meta-analysis on surface and drip fertigation for annual crops under different fertilization levels. Agricultural Water Management 289: 108504.

EMBRAPA UVA E VINHO. 2025. Boletim meteorológico. Bento Gonçalves: Empresa Brasileira de Pesquisa Agropecuária.

FAO. 2022. FOOD AND AGRICULTURE ORGANIZATION. Top 10 Country Production.

FREITAS SE. 2021. Lixiviação de nitrato em colunas de solo afetada por textura, doses de nitrogênio e lâmina de água adicionada. Dissertação (Mestrado em Agronomia. Botucatu: UNESP. 113p.

GAO X et al. 2024. Eleven-Year Canopy Nitrogen Addition Enhances the Uptake of Phosphorus by Plants and Accelerates Its Depletion in Soil. Forests 15: 416.

GLUHIĆ D. 2022. The importance and role of sulfur in grapevine fertilization. Glasnik Zaštite Bilja 45: 97-102.

IBGE. 2023. INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. Produção de Uva no Rio Grande do Sul.

INMET. 2025. INSTITUTO NACIONAL DE METEOROLOGIA. "Normais Climatológicas do Brasil (1981-2010) – Precipitação Acumulada Mensal e Anual" Brasília. Disponível em: https://portal.inmet.gov.br/normais. Acesso em: 24 de novembro de 2025.

KOOHKAN H & MAFTOUN M. 2016. Effect of nitrogen– boron interaction on plant growth and tissue nutrient concentration of canola (*Brassica napus* L.). Journal of Plant Nutrition 39: 922–931.

LEE J et al. 2005. Determination of total monomeric anthocyanin pigment content of fruit juices, beverages, natural colorants, and wines by the pH differential method: collaborative study. Journal of AOAC International 88: 1269-1278.

MALAVOLTA E et al. 1997. Avaliação do estado nutricional das plantas; princípios e aplicações. 319p.

MAPA. 2018. Instrução Normativa nº 14, de 08 de fevereiro de 2018. Diário Oficial da União, Brasília: MAPA.

MATIC P et al. 2017. Validation of spectrophotometric methods for the determination of total polyphenol and total flavonoid content. Journal of AOAC International 100: 1795-1803.

MELLO LMR de & MACHADO CAE. 2022. Vitivinicultura brasileira: panorama 2021.

MOTA MR et al. 2015. Fontes estabilizadas de nitrogênio como alternativa para aumentar o rendimento de grãos ea eficiência de uso do nitrogênio pelo milho. Revista Brasileira de Ciência do Solo 39: 512-522.

NACHTIGALL GR. 2012. Enfoque e resultados de pesquisa em nutrição de macieiras na Embrapa.

NIGON LL et al. 2025. Factors affecting potassium retention in sandy soils. Soil Science Society of America Journal 89: e70094.

NOVAIS RF et al. 2007. Fertilidade do solo. Sociedade Brasileira de Ciência do Solo.

PALARETTI LF & ROZANE DE. 2025. Aspectos relevantes sobre a fertirrigação em vinhedos. In: BRUNETTO G et al. Estratégias de manejo da fertilidade do solo e da nutrição de videiras. Sociedade Brasileira de Ciência do Solo. 524 p.

PASLEY HR et al. 2019.A taxa de fertilização nitrogenada aumenta a absorção pelas plantas e a disponibilidade de nutrientes essenciais no solo em produção contínua de milho no Quênia e no Zimbábue. Nutr Cycl Agroecosyst 115: 373–389.

PEREIRA GA et al. 2018. Modification and validation of Folin-Ciocalteu assay for faster and safer analysis of total phenolics content in food samples. Brazilian Journal of Food Research 9: 125-140.

PEREIRA VGM de F et al. 2019. Irrigação e fertirrigação no desenvolvimento de eucalipto. Ciência Florestal 29: 1100-1114.

PREZOTTI LC & GUARÇONI A. 2013. Guia de interpretação de análise de solo e foliar. Vitória. Incaper. 104p.

RIBEIRO BN et al. 2022. Leaching and availability of potassium in soil affected by conventional and coated fertilizer sources. Revista Brasileira de Engenharia Agrícola e Ambiental 26: 924-929.

ROZANE DE et al. 2020. Diagnóstico Composicional de Nutrientes (CND) aplicado a videiras cultivadas em região de clima subtropical. Horticultura 6: e56 2020.

SARKIS LF et al. 2024. Soil organic matter influences the agronomic efficiency of boron fertilizers in sandy Oxisol cultivated with soybean. Scientia Agricola 81: e20230231.

SILVA DJ & SOARES JM. 2009. Fertirrigação. In: SOARES JM & LEAO PCS. (Ed.). A vitivinicultura no Semiárido brasileiro. Brasília: Embrapa. p.483-512.

STRECK EV et al. 2018. Solos do Rio Grande do Sul. 3.ed., Porto Alegre: Emater/RS-Ascar.

TECCHIO MA et al. 2021. Manejo nutricional implica conhecimento sobre condições do solo e necessidades da planta. Visão Agrícola 14: 28-32.

WANG J et al. 2024. Efeitos de fertilizantes contendo potássio no metabolismo de açúcares e ácidos orgânicos em uvas. International Journal of Molecular Sciences. 25: 2828.

YAO G. et al. 2024. Effects of Calcium and Magnesium on Phosphorus Availability in Ferralsols and Rice Production in Forest Zones of Côte d'Ivoire. Journal of Agricultural Chemistry and Environment 13: 33-53.

YUE Y et al. 2025. Research progress on the regulation of grape quality by calcium fertilizer. Vitis 64: 8p.

ZANIN L et al. 2022. Effects of the Fractionation of the Nitrogen Fertilization on Root Nitrate Uptake and Vine Agronomic Performance in Pinot Gris Grapevines in a Temperate Climate. J Soil Sci Plant Nutr 22: 4996–5008.

ZENEBON O & PASCUET NS. 2005. Métodos físicoquímicos para análise de alimentos. São Paulo: Instituto Adolfo Lutz. 1018p.

ZOU R et al. 2025. Flavonoid biosynthesis facilitates low nitrogen adaptation in Gleditsia sinensis seedlings: Insights from comprehensive physiological and omics analyses. Plant Physiology and Biochemistry: 110446.