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A Study of the Relationship between Initial Grape Yield and Soil Properties Based on Organic Fertilization

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Abstract: Increasing the use of organic fertilizers is an effective measure to improve, increase soil fertility and maintain crop yields. The aim of this study was to investigate the influence of different types of organic fertilizers on the early yield of grapes and soil parameters, as well as the relationship between soil parameters and grape yield under fertilization conditions. The 'Shine Muscat' grape was used as the material, with early maturing cultivation in the solar greenhouse. From the time of grape planting, three-year continuous fertilization management was carried out using five types of base fertilizers: chemical fertilizer (CK), fermented corn stalk residue (A1), mature sheep manure (A2) and two types of commercial organic fertilizers (B1 and B2). In the third year, berry and soil samples were collected to determine grape yield and evaluate soil physicochemical properties, nutrient status and changes in enzyme activity, studying the relationship between grape yield and soil indicators. The results show that compared to CK, the grape yields with B1 and B2 increased by 19.04% and 16.26%, respectively, while A1 and A2 decreased by 24.09% and 18.97%. Organic fertilizer application reduced soil bulk density, increased soil porosity, enhanced soil organic matter content and effectively buffered soil pH levels. Two types of commercial fertilizers (B1 and B2) improved soil total nitrogen, total phosphorus, total potassium, available nitrogen and available phosphorus content to varying degrees. All organic fertilizer treatments effectively increased soil enzyme activity, except for soil sucrase activity. Through correlation and regression analyses, it was found that in this study, the levels of available nitrogen, available potassium and soil saccharase activity were most closely related to early grape yield. Their influence on grape yield was in the order of available nitrogen > soil saccharase activity > available potassium. Therefore, with a combined organic and inorganic basal fertilization system, the fertilizer nutrients are more comprehensive and help to increase the productivity of grapes at the beginning of the fruiting period. Nitrogen and phosphorus are very important in the maintaining of grape yields and improving sucrose activity in the soil through the application of organic fertilizers cannot be ignored when increasing yields.

Keywords: grape yield; mineral fertilization; organic fertilizer; regression analysis; soil enzyme activity; soil nutrients

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1. Introduction

Fertilization, as a global soil quality improvement strategy, plays a key role in ensuring high agricultural yields [1]. The application of chemical fertilizer is an important factor driving significant increases in global crop yields. In recent decades, growers have maintained soil productivity by applying chemical fertilizer in large quantities to achieve high yield management of farmland [2]. However, the long-term over-application of chemical fertilizer has led to a series of agro-environmental and ecological security problems such as water pollution, soil pollution and increased greenhouse gas emission [3–5]. In fruit tree production, the excessive application of chemical fertilizer has caused soil salinization, sloughing, nutrient imbalance, low organic matter content and accumulation of harmful microorganisms [6–10]. For this reason, organic fertilizers have been proposed as an alternative to chemical fertilizers in the fight against soil problems and the maintenance of soil health.

Many studies have shown that increased application of organic fertilizer can promote the formation of soil granular structure, improve soil physical structure, enhance soil microbial activity, promote nutrient uptake by the root system and enhance soil productivity. A survey in Italy showed that fertilizer management with organic manure can be a valuable alternative to the traditional mineral fertilization of nectarine trees grown in the Po River Basin [11]. The application of organic fertilizer can increase the soil organic matter content, and since it is rich in a variety of crop nutrients, can make up for the shortcomings of chemical fertilizer in terms of single nutrient which can cause soil deficiency, crusting and low nutrient utilization [12]. The results of the study on bananas showed that the application of organic fertilizer significantly increased soil organic carbon content and enzyme activity, root length density, plant biomass and nutrient uptake [13]. Zhu et al. studied different fertilizer treatments in apple orchards for four consecutive years and the results showed that organic fertilizer applied alone or in combination with chemical fertilizer could improve soil fertility and the functional diversity of soil microbial communities. Nitrogen, phosphorus and potassium fertilizers with organic fertilizers are more effective than chemical fertilizers alone in improving the quality of soil microbial communities [14]. Reasonable alternative management of organic fertilizer can effectively alleviate soil acidification and nutrient deficiencies in tea plantations, increase soil organic matter and ammonium nitrogen content and improve tea yield and quality [15]. The combination of reduced fertilizer and bio-organic fertilizer can effectively increase soil fertility, improve soil microbial community structure and increase the yield and quality of lettuce [16]. Belay et al. showed that long-term inorganic fertilization did enhance the total organic carbon content of the soil and significantly increased grain yield in maize [17]. Excessive use of chemical fertilizer can lead to the accumulation of nitrates in vegetable products—this negative impact can be mitigated by reducing the amount of chemical fertilizer used and combining them with organic fertilizer that have better nutritional properties [18–20]. In grape production, the application of organic fertilizers ensures the supply of organic carbon, improves the organic matter content in the soil and promotes soil microorganisms [9,21]. The combined use of compost, mineral fertilizers and microbial agents promotes root development and improves soil quality in table grapes [22]. Considering cost, human health, food safety and sustainable viticulture, the use of organic fertilizer was superior compared to N-P-K fertilizer in producing high-quality grapes [23].

Base fertilizer accounts for about 70% of the annual fertilizer application of fruit trees in China and is the most important method of fertilizer application. In the past, most of the base fertilizer for fruit trees consisted of farmyard manure and slow-acting chemical fertilizer. However, in recent years, the application of agricultural waste such as straw, tailing vegetables, etc. for fermentation, reuse and bio-organic fertilizer has gradually become common. Studying the impact of organic fertilizers in place of chemical fertilizers in fruit tree production on tree yield, soil properties and nutrient levels is of significant importance for the green and efficient production of fruit trees, as well as for the sustainable development of the fruit tree industry. Reducing chemical fertilizer inputs and adding organic matter are effective measures to improve soil ecology and maintain soil fertility. However, different types of organic fertilizers have variable fertilizer efficacies. Furthermore, combinations of fertilization, soil properties and soil nutrients have complex effects on crop productivity. However, it is unclear how these variables affect crop productivity and their relationship to yield. For this reason, we conducted this experimental study on the application of organic fertilizer to grapevines. In the newly constructed grape solar greenhouse, different types of organic fertilizer were applied as basal fertilizer for three consecutive years from seedling planting to the first grape harvest to study the effects of the type of basal fertilizer on grape yield and soil biochemical indicators and their relationship, for the implementation of grape production of chemical fertilizer reduction measures, to provide a theoretical basis and practical references.

2. Materials and Methods

2.1. Study Site and Material

The experiment was carried out in an agricultural garden in Gucheng Town (102°42′4.13″ E; 37°46′1.73″ N), Liangzhou District, Wuwei City, which is located at the eastern end of the Hexi Corridor of Gansu Province. The area has a typical temperate continental arid climate, with little rain, mean annual temperature of 7.7 °C, mean annual sunshine hours of 2873.4 h, mean annual precipitation of 100 mm and annual evaporation of 2020 mm. In the Chinese soil classification standard, the soil type here is sierozem soil [24]. Before the greenhouse was built, the land was a wheat field that had been abandoned for more than nine years. Irrigation water comes from rainwater and snowmelt stored in a reservoir. The agricultural garden where the experimental greenhouse is located is operated and managed by Wuwei Wanhua Jinfeng Agricultural Development Co.

The test material are 'Shine Muscat' grapes, a rose-scented grape variety popular with consumers in East Asia. They are currently widely planted and developing rapidly in China [25]. The experimental grapevines were cultivated in solar greenhouses from 2020 to 2022 using the method of promoting early cultivation, with an area of 0.03 ha per greenhouse. Each greenhouse was planted with a row of grapes on a flat trellis with a height of 2.0 m. The grapes were planted on a ridge 30 cm high and 50 cm wide, with a spacing of 3.5 m. Grapes break dormancy and start growing at the end of February and fruit ripening and harvesting takes place at the end of August, with irrigation by high water flooding on both sides. The experimental greenhouse can be seen in Figure 1.

Figure 1. Exterior and interior view of experimental solar greenhouse.

2.2. Experimental Treatment

The experiment had five basal fertilizer treatments, each in five greenhouses built in the same year, with one fertilizer treatment per greenhouse. The greenhouse specifications and environmental settings were identical. Grape production was managed under a uniform technology according to the defined production standards. The management conditions were identical except for the base fertilizer applied. The five experimental treatments were specified as:

(i) Control (CK): 15 kg each plant, ternary compound fertilizer, produced by Stanley Agricultural Group Inc. (Linyi, Shandong, China) $N:P_2O_5:K_2O$ = 15:20:5, total nutrients ≥ 40%. Packaging specification is 50 kg/bag.

(ii) Maize straw (A1): 0.5 m^3 each plant, crushed and added with strain of Shiming Bio-Reactor Strain 001 for fermentation [26], produced by Shandong Tianhe Bioengineering Technology Co. (Jinan, Shandong, China)

(iii) Sheep manure (A2): 0.5 m^3 each plant, sheep manure naturally composted and rotted.

(iv) Commercial organic fertilizer (B1): 15 kg each plant, produced by Parch Bio Ltd. (Gongyi, Henan, China) with fertilizer, containing mineral potassium xanthate ≥50%, potassium chloride ≥12%, Humic acid content ≥55%, organic carbon content ≥25%. Packaging specification is 10 kg/bag.
(v) Commercial organic fertilizer (B2): 15 kg each plant, produced by Angie's Yeast Co. (Yichang, Hubei, China) with organic matter content ≥40%. The number of effective living bacteria ≥0.2 billion. g^{-1}, packaging specification is 20 kg/bag.

In our experimental setup, each treatment consisted of 3 plants with 5 replications, making a total of 15 plants per treatment. Different basal fertilizers were applied annually for three consecutive years. The application method involved creating a furrow 1.5 m long and 40 cm deep located 40–60 cm from the vines on both sides of the ridge, with the distance increasing each year. The fertilizer was mixed with the soil within this furrow and evenly distributed in September. When the grape berries ripened in the third year, the yield was measured; at the same time, soil samples were collected to determine soil parameters.

2.3. Grape Yield Determination

During the third year of the study, once the grape berries had reached full maturity at the end of August, a comprehensive harvest was conducted to measure the yield. All grape clusters from each treatment and replication were collected to ascertain the total production, which was then converted to a per-hectare basis.

2.4. Soil Sample Collection and Nutrient Determination

Soil sampling was conducted concurrently with the fruit harvest, utilizing a random sampling method. On either side of the fertilization furrow and at a distance of 50 cm from the grapevines, soil cores were extracted from the area where the root system was densely distributed (between 20–60 cm below the ground surface). For each treatment, 15 soil samples were collected, which were then thoroughly mixed to create a composite sample, ensuring homogeneity. The soil samples were then brought back to the Fruit Tree Physiology Laboratory (College of Horticulture, Gansu Agricultural University) in a low-temperature incubator, sieved through a 2 mm sieve, and air-dried at room temperature for the determination of soil nutrients and soil enzyme activities.

Soil bulk weight was measured by ring knife method, soil porosity = (1 − bulk weight/specific gravity) × 100%. The soil pH and electric conductivity (EC) were determined at a soil:water ratio of 1:5 with a conductivity meter (Shanghai Leici, DDS-307, Shanghai, China).

The soil properties were determined using routine analytical method [27]. The soil total nitrogen content was determined using the Kjeldahl method, total phosphorus content was determined using the molybdenum blue colorimetric method, and total potassium content was measured using the flame spectrophotometer method. The available nitrogen content was determined using the alkaline diffusion method, available phosphorus was extracted with sodium bicarbonate ($NaHCO_3$) and determined using the molybdenum antimony colorimetric method and available potassium was extracted with acetamide and determined using the flame photometric method. The soil organic matter content was measured using the dichromate-sulfuric acid (K_2CrO_7-H_2SO_4) oxidation method [28].

2.5. Soil Enzyme Activities

Soil catalase activity was determined by potassium permanganate titration. Soil saccharase activity was determined using the 3,5-dinitrosalicylic acid colorimetric method, soil urease activity was determined using the indophenol colorimetric method, soil alkaline phosphatase activity was determined using the disodium benzoate colorimetric method and soil dehydrogenase activity was determined using the TTC reduction method [29].

2.6. Statistical Analysis

The data were analyzed using SPSS Statistics 22. One-way analysis of variance (ANOVA) was used to analyze the data, and Duncan analysis was performed to determine the significance of differences between treatments. Pearson correlation coefficients were calculated for soil parameters and grape yield and multivariate regression analysis was used to assess both relationships. Heat map of Pearson's correlation coefficient matrix and bar diagrams were constructed using Origin 2021.

3. Results

3.1. Grape Yield

Three consecutive years of using different organic fertilizers as base fertilizers had a great impact on grape yield at the beginning of the fruiting season (Table 1). The highest grape yield was obtained in treatments B1 and B2. There was no significant difference between the two types of commercial fertilizers and the yields of the other treatments were in the range of high to low in CK, A2 and A1. Compared to CK, the yield of A1 and A2 treatments decreased by 24.09% and 18.97%, respectively; B1 and B2 increased by 19.04% and 16.26%, respectively. The use of commercial fertilizer as basal fertilizer resulted in a significant increase in yield compared to chemical fertilizer, while the application of sheep manure and corn stover in the early stage of grape fruiting resulted in a significant decrease in yield compared to chemical fertilizer.

Table 1. Grape yield of different fertilizer treatments.

Treatment	Yield/(kg·ha^{-1})	Compared with CK	
		Increased Yield/(kg·ha^{-1})	Yield Increasing Rate/%
CK	10,824.30 b	/	/
A1	8211.39 d	−2612.91 b	−24.09 b
A2	8761.83 c	−2062.47 b	−18.97 b
B1	12,883.35 a	2059.05 a	19.04 a
B2	12,583.32 a	1759.02 a	16.26 a

Note: Different letters in same column indicate significant differences among treatments ($p < 0.05$).

3.2. Soil Physicochemical Properties

As shown in Figure 2, CK had the highest bulk density and the smallest porosity, A1 treatment had the lowest bulk density and the smallest porosity and A2, B1 and B2 were in between. There was no significant difference in bulk density and porosity among the treatments. Compared to CK, the bulk density of the A1 treatment was reduced by 32.17% and the porosity was increased by 24.75%, which can be seen by the fact that applying organic fertilizer can significantly reduce the bulk density of the soil and make it loose and porous. The pH value of CK was the highest, followed by A1, B1 and B2 treatments, and there was no significant difference between them. A2 treatment was the lowest, reduced by 10.26% compared with CK, and the other fertilizer treatments were reduced by an average of 7.68%. This means that the organic fertilizer had the effect of lowering the pH of the soil compared with chemical fertilizer. Soil EC values were CK > B1 > B2 > A2 > A1, indicating that CK had the highest concentration of soluble salts in the soil and the B1, B2, A2 and A1 treatments were reduced by 15.83%, 26.97%, 43.74% and 58.98%, respectively, compared with CK.

3.3. Soil Nutrients

The soil nutrient contents under different fertilizer treatments were shown in Figure 3. It was observed that the total nitrogen, total phosphorus and total potassium contents were highest in B1 and lowest in A1. There was no significant difference between B2 and CK. Compared with CK, the soil total nitrogen, total phosphorus and total potassium contents of B1 increased by 23.53%, 37.63% and 20.96%, respectively, while the A1 decreased by

35.29%, 34.41% and 29.56%. The available nutrient content of the soil was also highest in B1. Soil available nitrogen, available phosphorus and available potassium contents of B1 were higher than that of CK by 35.29%, 34.41% and 29.56%, respectively. All four organic fertilizer treatments (B1, B2, A2 and A1) had significant effects on the enhancement of soil organic matter content. Among these, B1 was the most effective, with organic matter content that was nearly double that of the control (CK).

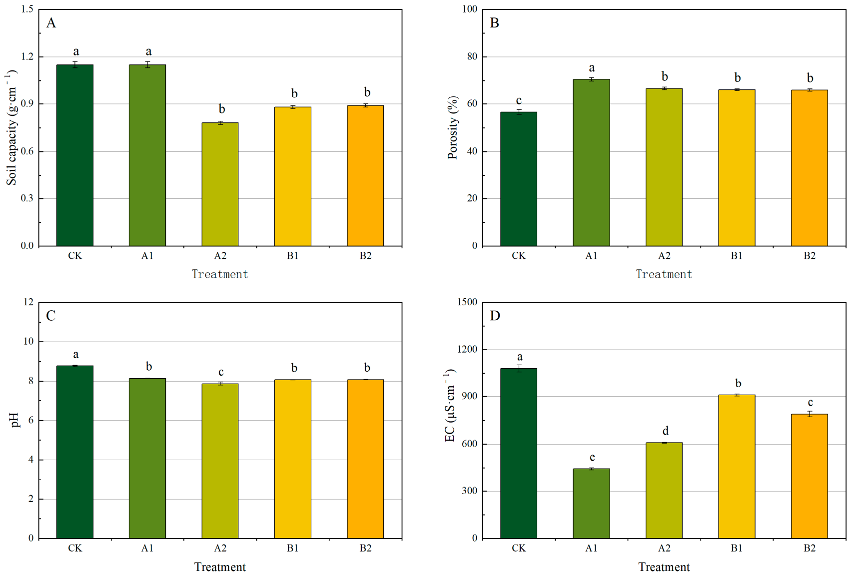

Figure 2. Effects of fertilizer treatment on soil physicochemical properties. The (**A**–**D**) diagrams in the figure are soil capacity, porosity, pH and EC, each in turn. Note: different lowercase letters indicate significant difference ($p < 0.05$).

3.4. Soil Enzyme Activity

Soil catalase activity was B1 > B2 > A2 > A1 > CK, with significant differences between treatments (Figure 4A). Soil dehydrogenase activity was highest in the B1 and A1 treatments, followed by B2, then A2 and CK (Figure 4B). Soil saccharase activity was in the order of A2 > A1 > B1 > B2 > CK, from high to low (Figure 4C). Soil urease activity was highest in B1, lowest in CK and 43.86% higher in B1 than CK. A1, A2 and B2 were in the middle, and there was no significant difference (Figure 4D). Soil alkaline phosphatase activity was significantly different between the control and the four treatments, and was highest in A1 and lowest in CK (Figure 4E). Comprehensively, the application of organic fertilizer could improve soil enzyme activity.

3.5. Correlation Analysis between Grape Yield and Soil Indicators

The results of correlation analysis between grape yield and soil indicators under different types of basal fertilizers are shown in Figure 5. The grape yield was significantly and positively correlated with soil EC, total nitrogen, total phosphorus, total potassium, available nitrogen, available phosphorus and available potassium content ($p < 0.05$), and significantly and negatively correlated with soil saccharase activity ($p < 0.05$). Soil bulk density was significantly and positively correlated with pH and EC ($p < 0.05$) and significantly negatively correlated with soil porosity, organic matter content and catalase, dehydrogenase, saccharase and alkaline phosphatase activities ($p < 0.05$). Soil urease activity was significantly positively correlated ($p < 0.05$) with total nitrogen, total phosphorus, total potassium, available nitrogen, available phosphorus, available potassium and organic matter content.

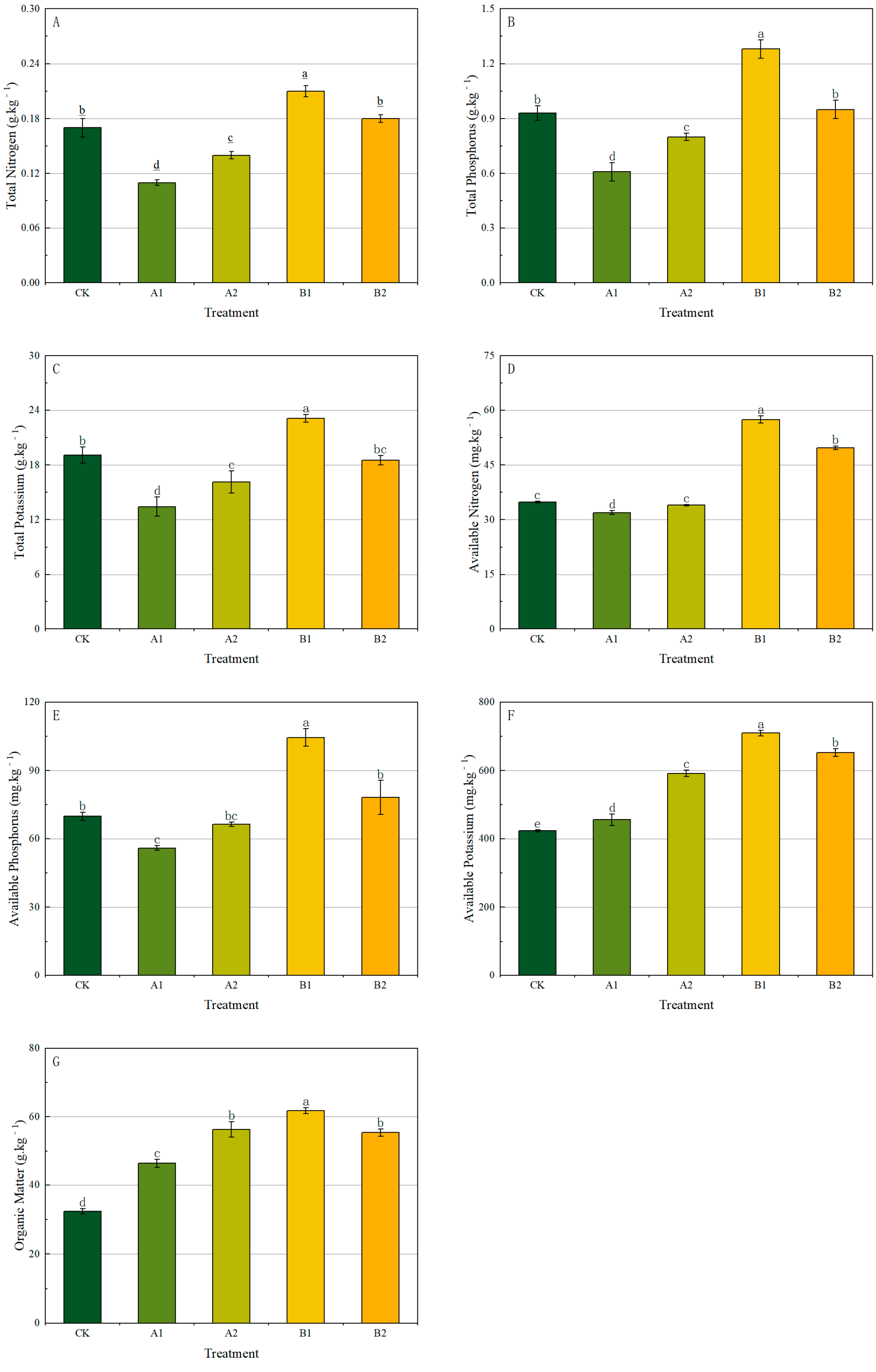

Figure 3. Nutrient contents of vineyard soil under different fertilizer treatments. The (**A**–**G**) diagrams in the figure are total nitrogen, total phosphorus, total potassium, available nitrogen, available phosphorus, available potassium, organic matter, each in turn. Note: Different letters indicate significant differences among treatments ($p < 0.05$).

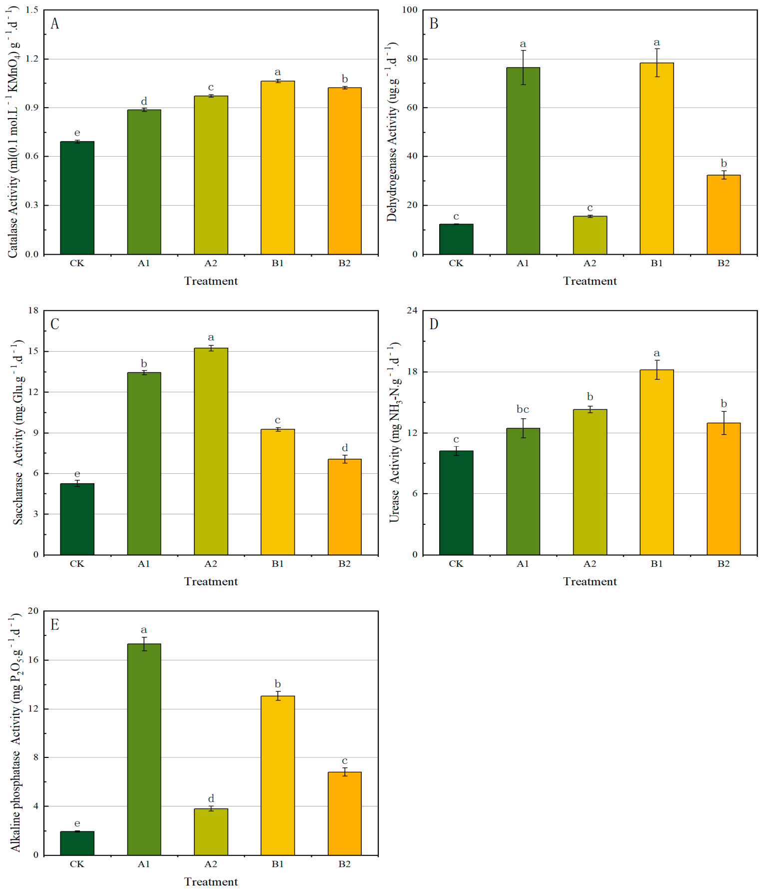

Figure 4. Enzyme activities of vineyard soil under different fertilizer treatments. The (**A**–**E**) diagrams in the figure are soil catalase, dehydrogenase, saccharase, urease, alkaline phosphatase, each in turn. Note: Different letters indicate significant differences among treatments ($p < 0.05$).

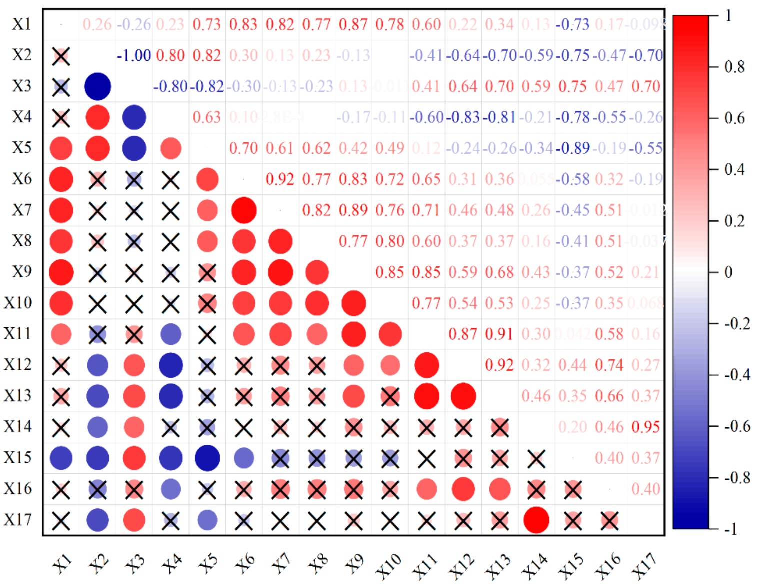

Figure 5. Analysis of correlation between grape yield and soil indexes. Note: X1–X17 are yield, bulk density, porosity, pH, EC, total nitrogen, total phosphorus, total potassium, available nitrogen, available phosphorus, available potassium, organic matter, catalase, dehydrogenase, saccharase, urease, alkaline phosphatase, in turn. Red dots indicate positive correlation, blue dots indicate negative correlation, shade of colour indicates strength of correlation, "×" indicates weak or no correlation. Data was correlation coefficient.

3.6. Multiple Linear Regression Analysis of Grape Yield and Soil Indicators

The grape yield was used as the dependent variable and the eight soil indicators (X5, X6, X7, X8, X9, X10, X11 and X15) were used as independent variables. Linear fitting and analysis was carried out to verify the linear relationship (Table 2). The validation results showed that the eight soil indicators had significant effects on the dependent variable (yield) under fertilization treatments, the F values of the linear fitting models reached the highly significant level.

Table 2. Analysis of linear fitting.

Index	R	R^2	Corrected R^2	F	Sig.
X5	0.688	0.474	0.433	11.702	0.005
X6	0.821	0.674	0.648	26.829	0.000
X7	0.801	0.642	0.614	23.313	0.000
X8	0.724	0.539	0.503	15.182	0.002
X9	0.878	0.771	0.754	43.877	0.000
X10	0.739	0.547	0.512	15.686	0.002
X11	0.608	0.370	0.321	7.622	0.016
X15	0.742	0.551	0.516	15.943	0.002

Note: dependent variable is grape yield. Note: X5 is EC, X6 is total nitrogen, X7 is total phosphorus, X8 is total potassium, X9 is available nitrogen, X10 is available phosphorus, X11 is available potassium and X15 is saccharase.

The scatter plot of soil parameters on grape yield (Figure 6) revealed that yield and soil EC, total nitrogen, total phosphorus, total potassium, available nitrogen, available phosphorus, available potassium and saccharase showed a clear linear trend. Therefore, a regression model of grape yield and soil parameters such as those above was considered.

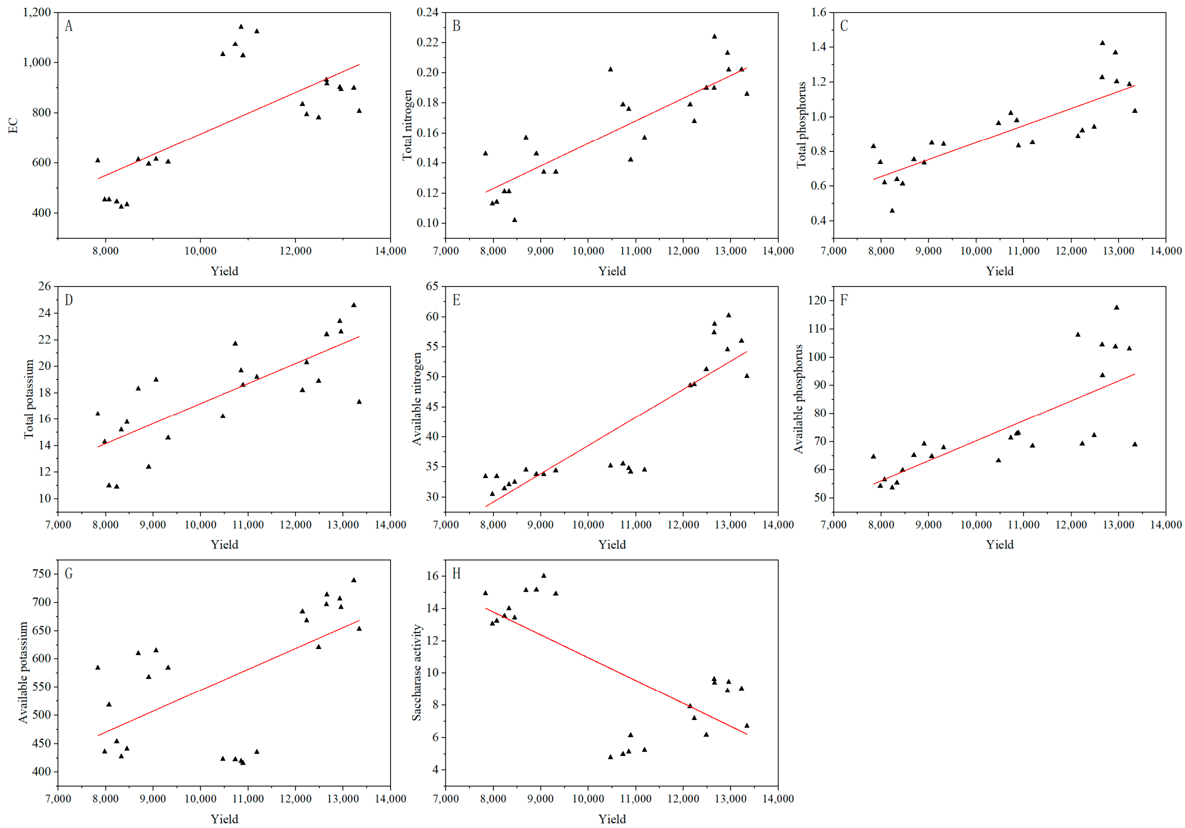

Figure 6. Linear fit scatter plot of soil parameters to grape yield. The (**A**–**H**) diagrams in the figure are soil EC value, total nitrogen, total phosphorus, total potassium, available nitrogen, available phosphorus, available potassium, soil saccharase, each in turn.

The linear relationship between grape yield and soil parameters (X5, X6, X7, X8, X9, X10, X11 and X15) was fitted using stepwise regression analysis to establish the optimal regression equation. As seen in Table 3, with stepwise regression, R, R^2 and corrected R^2 gradually increased while the standard error of the predicted value gradually decreased, indicating that the fit of the regression equations gradually improves and the F-value of the three regression equations reaches a highly significant level. The corrected R^2 of regression model 3 was 0.955, meaning that X6, X15 and X11 were able to explain 95.5% of the causes of changes in grape yield, which was a good fit. The remaining variables were excluded due to the non-significant F-test. The DW was 2.200, indicating that model 3 satisfied the requirement of sample independence for linear regression.

Table 3. Model summary for multiple regression.

Model	R	R^2	Corrected R^2	Standard Error of Prediction	Durbin-Watson (DW)
1	0.888 [a]	0.789	0.780	928.649	
2	0.974 [b]	0.949	0.944	469.358	
3	0.980 [c]	0.961	0.955	420.451	2.200

Note: [a] predictors: (constant), X6; [b] predictors: (constant), X6, X15; [c] predictors: (constant), X6, X15, X11; dependent variable: yield.

The results of model multicollinearity validation were shown in Table 4 where the VIF values of X6, X15 and X11 in Model 3 were less than 10, indicating that there was no collinearity between soil parameters. Figure 7 showed that the regression standardized residuals basically conformed to normal distribution. It was verified that linear regression Model 3 meets the assumptions of sample independence, multicollinearity and residual normality.

Table 4. Coefficient listings and covariance tests for multiple linear regression.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Covariance Statistic	
		B	Standard Error	Beta			Tolerance	VIF
1	Constant	3603.658	781.604		4.611	0.000		
	X6	169.566	18.263	0.888	9.285	0.000	1.000	1.000
2	Constant	7205.244	588.818		12.237	0.000		
	X6	136.621	10.057	0.716	13.584	0.000	0.842	1.187
	X15	−222.174	26.935	−0.435	−8.248	0.000	0.842	1.187
3	Constant	7352.479	530.658		13.855	0.000		
	X6	80.712	23.841	0.423	3.385	0.003	0.120	8.314
	X15	−287.080	35.197	−0.562	−8.156	0.000	0.396	2.526
	X11	4.993	1.971	0.291	2.533	0.019	0.143	7.012

Note: Dependent variable was grape yield.

In this study, the regression equation for soil parameters and grape yield could be expressed as:

$$\text{Yield (Y)} = 7352.479 + 80.712 \times X6 + 4.993 \times X11 - 287.080 \times X15 \quad (1)$$

The order in which the variables were listed in the table indicates the relative magnitude of their effect on grape yields, as could be seen by the degree of effect on grape yield in the order of available nitrogen content (X6), saccharase activity (X15) and available potassium content (X11). The effects of available nitrogen (X6) and available potassium (X11) on the grape yield were positive, meaning that as their content increased, the yield was higher. Saccharase activity (X15) had a negative effect on yield.

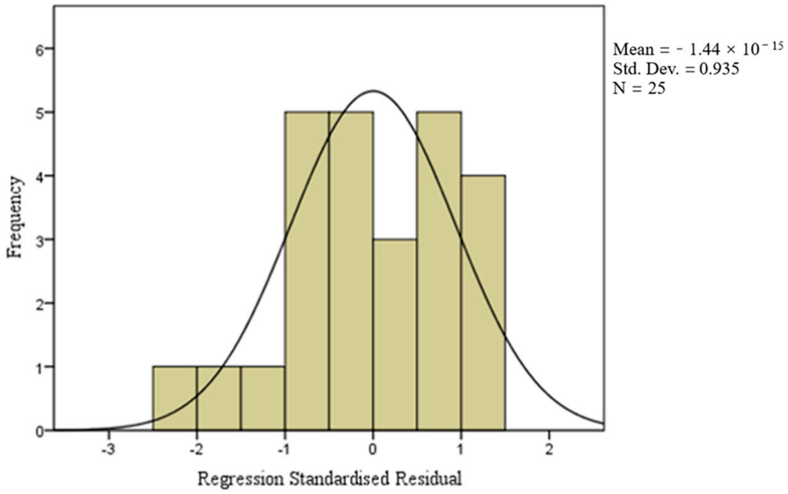

Figure 7. Histogram of residual distribution of multiple linear regression. Note: dependent variable is grape yield.

4. Discussion

4.1. Effect of Organic Fertilizer on Grape Yield

Previous studies have shown that the combined application of organic and inorganic fertilizer significantly increased crop yield [30]. Maize and soybean yields were improved by commercial organic fertilizers [31]. Under drip irrigation, the use of organic amendments increased the grape yields [32]. Some studies also showed that replacing synthetic fertilizer with organic fertilizer above a certain percentage reduces crop yields in the first few years [33–36]. In this study, grape yields were reduced in both A1 and A2 treatments compared to CK, while yields increased in two commercial organic fertilizers (B1 and B2). Commercial organic fertilizers were formulated from plant straw, animal manure and other resources rich in organic matter with the addition of various elements, with thorough fermentation, relatively stable quality, removal of toxic and harmful substances and more comprehensive nutrients [37,38]. This could be the reason for the lower grape yield compared to chemical and commercial organic fertilizers, as the maize stover and sheep manure were single organic fertilizers with less effective nutrients. The study confirmed that the compound fertilizers containing both organic and inorganic nutrients (e.g., commercial organic fertilizer) were more beneficial for grape yield.

4.2. Effect of Organic Fertilizer Application on Soil Physicochemical Properties

Numerous studies have shown that organic fertilizer can reduce soil bulk density and increase soil organic carbon content, laying the foundation for soil fertility enhancement [39–41]. The results of this study showed that there were significant changes in soil chemistry after the application of organic fertilizer as compared to the application of chemical fertilizer. Specifically, the application of organic fertilizer significantly reduced the soil bulk weight compared to CK, with the lowest soil bulk weight under the A1. Soil porosity and soil bulk density were opposite, as soil in the CK group had the least porosity. The maximum porosity difference between the treatments was 14% (Figure 2). It could clearly be seen that organic fertilizer increases the soil humus, changes the soil structure and makes the soil loose and porous.

The pH and EC were significantly lower in the four treatment groups (A1, A2, B1 and B2) compared to the values in the control (CK) group (Figure 2). The application of organic fertilizers reduced the alkalinity of vineyard soils, which was inconsistent with previous studies [42,43]. In acidic soils, the application of organic matter can slow down soil acidification. In alkaline soils, organic matter has a good buffering and regulating effect on soil acidity and alkalinity, especially through the action of microorganisms, which can maintain the pH balance.

Fertilizer (chemical and organic fertilizer) application can increase soil EC due to the nutrients and salts contained in organic matter [44,45]. In the case of this study, the EC values of soil under different fertilization treatments showed significant differences and the soil EC values were ranked in the order of CK > B1 > B2 > A2 > A1 (Figure 2). Chemical fertilizer had a higher ionic content compared to organic fertilizer. The higher the proportion of chemical fertilizer in the mix, the greater the soil EC value.

4.3. Effect of Organic Fertilizer Application on Soil Fertility and Enzyme Activities

Soil total nitrogen, total phosphorus and total potassium, as well as available nitrogen, available phosphorus and available potassium contents of B1 were significantly higher than CK and were the highest among the four treatment groups. Meanwhile, the total nitrogen, total phosphorus and total potassium, as well as the available nitrogen and phosphorus contents of A2 and A1 were significantly lower than those of CK. However, the phosphorus and potassium contents were higher than those of CK (Figure 3). Application of commercial organic fertilizer was better than farmyard manure because the commercial organic fertilizer was more comprehensive in nutrients than farmyard manure and crop straw and resulted in more complete fermentation, more stable quality, non-toxicity, lack of harm, etc. [46,47].

Organic fertilizers serve as a vital contributor to the soil organic matter, playing a crucial role in preserving soil fertility and enhancing its characteristics [1,33]. In this study, soil organic matter content was significantly higher in all four organic fertilizer treatments than in CK and the highest B1 treatment was about twice as high as CK (Figure 3). The findings align with prior research which established organic fertilization as one of the most efficacious strategies for elevating the levels of soil organic matter [48,49].

As a kind of biocatalyst in soil, soil enzymes are directly or indirectly involved in the conversion and decomposition of soil organic carbon, nutrient cycling and decomposition of harmful substances in the soil biochemical cycle [36]. The level of soil enzyme activity determines, to a certain extent, the effectiveness of soil nutrients. Soil fertilization practices and their types can change the rate at which soil biochemical reactions occur by improving soil enzyme activity. The results of this study showed that application of organic manure significantly increased the activities of soil catalase, soil dehydrogenase, soil sucrase, urease and alkaline phosphatase compared to CK (Figure 4). This is mainly because organic fertilizer increases the soil organic carbon and nitrogen stocks which induces an increase in enzyme activity by increasing the substrate in the enzymatic reaction [50,51]. The comparison of different organic fertilizers revealed that that soil peroxidase and urease activities were higher in soil treated with commercial organic fertilizer, while soil glycosidase activities were higher in soils treated with corn stover and sheep manure, which is consistent with the results of previous studies [23].

4.4. Relationship between Grape Yield and Soil Parameters after Application of Organic Fertilizer

There are numerous soil factors that affect yield in crop production. Correlation analysis provides an effective way to address this issue. In the case of this study, grape yield was significantly and positively correlated ($p < 0.05$) with soil EC, total nitrogen, total phosphorus, total potassium, available nitrogen, available phosphorus and available potassium content, and negatively correlated ($p < 0.05$) with soil sucrase activity (Figure 5). The results were consistent with earlier findings [17,52].

The results of regression analysis demonstrated that available nitrogen, sucrase activity and available potassium were most closely associated with yield (Table 3). There was a highly significant linear relationship between the three and grape yield. The effect of available nitrogen and available potassium on grape yield was positive, while the soil sucrase activity was negative. Of these, available nitrogen content had the highest degree of influence on grape yield (Table 4). This was the reason why the application of nutrient-rich bio-organic and chemical fertilizer had higher yields, while the application of nutrient-poor sheep manure and maize stover resulted in lower grape yields. This study confirms that nitrogen is critical for plant pre-growth and nutrient accumulation and grape pre-nutrient accumulation is decisive for fruit yield.

5. Conclusions

The utilization of commercial organic fertilizers (contains chemical fertilizer, organic fertilizer and beneficial microorganisms) led to a significant enhancement in the initial harvest of grapes when compared to the use of chemical fertilizers alone, whereas the sole application of sheep manure and maize stover was found to decrease grape yields. The application of four organic fertilizers can significantly reduce soil bulk density, increase soil porosity, improve soil physical properties and improve soil organic matter content and soil enzyme activity. Soil nitrogen, phosphorus and potassium levels were higher with the two commercial organic fertilizers than with sheep manure and corn stover. There was a significant linear relationship between grape yield and soil parameters. Soil available nitrogen content, soil sucrase activity and available potassium content were important factors in determining grape yield. To sum up, the basal fertilization program combining organic and inorganic fertilizers in this study helped to increase early grape yield and maintain good soil properties. Among them, available nitrogen and phosphorus contents were critical for improving early grape yield, and the role of soil sucrose activity in influencing yield should not be neglected. Future research should prioritize investigating the long-term impacts of organic fertilizers on soil and grape yields as well as understanding the potential effects of climate change on grape cultivation.

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