Archives of Agriculture Sciences Journal
Print ISSN: 2535-1680
Online ISSN: 2535-1699

ARCHIVES OF AGRICULTURE SCIENCES JOURNAL
Volume 7, Issue 2, 2024, Pages 148–171

Available online at https://aasj.journals.ekb.eg

DOI: https://dx.doi.org/10.21608/aasj.2024.385599

Soil properties improvement and nitrogen leaching induced compost and mineral fertilization for maximizing grapevines production in arid regions, El-Minia, Egypt

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Abstract

In addition to being environmentally hazardous, using an excessive quantity of chemical nitrogen fertilizer to boost crop output is not economically viable. In this study, flame seedless grapevines were fertilized with chemical nitrogen fertilizer and compost for two seasons (2021 and 2022) to assess nitrogen (N) application from various sources for minimized nitrogen leaching and raised grapevine production. The results showed that applying compost as an organic nitrogen source, either at a rate of 100% or combined with 50% ammonia sulfate (fast-release) or 50% Enciabeen (slow-release), was highly effective in reducing soil bulk density, improving soil fertility and water movement, and controlling nitrogen loss compared to using nitrogen entirely in mineral form. Compared to 100% ammonia sulfate, co-applying mineral nitrogen fertilizer at 50% ammonia sulfate and 50% Enciabeen resulted in a significant yield increase of 18% in the first season and 43% in the second season. The results of principal component analysis revealed that co-applying mineral nitrogen fertilizer at a rate of 50% ammonia sulfate and 50% Enciabeen or co-applying 50% ammonia sulfate and 50% compost as an organic nitrogen source caused a gradual improvement in berry quality, increased Total soluble solid (TSS) %, berry weight, and dimensions, TSS/acid, and total sugars %. Moreover, co-applying slow- and fast-release fertilizers or combining mineral fertilizers with organic materials is the most effective approach to improving soil characteristics, increasing grape production, enhancing seedless grapevine quality, and reducing nitrogen loss. Adding compost to farmlands improved most physical and hydraulic soil properties, especially those with low organic matter and poor structure.

Keywords: compost, slow-release, nitrogen leaching, hydraulic conductivity, vineyard yield, reducing sugars.

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1. Introduction

Using an extensive quantity of chemical nitrogen (N) fertilizer to increase crop yield is not economically viable. It also causes environmental pollution and places a significant burden on farmers (Anas *et al.*, 2020). Thus, using organic fertilizers derived from farming practices may offer an alternative approach to energy conservation. Kühling *et al.* (2021) stated that nitrate leaching from fertilizer use depends on fertilizer type (organic or mineral), how it is applied, and the climate conditions. Organic farming can reduce the environmental impacts of NO_3-N leaching (Miliordos *et al.*, 2022). Gu *et al.* (2015) noticed that increased irrigation levels and N application rates resulted in high soil nitrate concentrations and N leaching at a depth of 2.0 m. They also mentioned that the subsoil's nitrate concentration was low due to manure application. According to Biernat *et al.* (2020), organic farming systems have lower nitrate leaching losses than conventional farming systems due to reduced nitrogen (N) inputs. The use of organic and biofertilizers with nitrogen minerals as fertilizer has been reported as a proposed strategy to reduce N losses from agricultural soils and enhance N-use efficiency by increasing soil organic matter content (Alessandrino *et al.*, 2021; Roozbeh and Rajaie, 2021). Using chemical fertilizers to compensate the inadequate soil fertility increases orchard management costs while polluting the environment. The NO_3-N is crucial in the early stages of growth, but it is not widely used as a fertilizer on its own; the other forms (NO_2-N and NH_4-N) are released into the atmosphere via nitrification (Robinson *et al.*, 2011). Various controlled-release fertilizers have been developed in the last few decades to improve fruit crops and nitrogen use efficiency. Khatab (2001) demonstrated that increasing nitrogen fertilizer rates enhanced NO_3 and NO_2 concentrations. He also noted that utilizing ammonium nitrate fertilizer causes high concentrations of NO_3 and NO_2 in drainage water, followed by urea and ammonium sulfate. The leached nitrate in the subsoil might lead to pyrite oxidation, which releases sulfate and other elements (Pahalvi *et al.*, 2021). Fernández-Escobar *et al.* (2004) noticed that total nitrogen losses by leaching were higher when adding ammonium nitrate and calcium nitrate than those of traditional nitrogen fertilizers (urea, ammonium sulfate, ammonium nitrate, calcium nitrate and slow-release nitrogen fertilizers). Crop productivity in arid and semi-arid regions, such as in Middle Egypt, is influenced by low inherent soil fertility and the large amounts of irrigation water required. Insufficient soil fertility, shortage of water, and extensive fertilization make these agro-ecosystems sensitive to the existing global changing climate process and cyclical drought events. Nitrogen (N) is an essential macronutrient for crop growth, development, and production. Mineral nitrogen fertilizers are commonly employed in traditional vineyard agricultural environments. Excessive utilization of chemical N fertilizers has the potential to lower soil organic matter (SOM) levels, soil degradation, and nitrate leaching in the soil environment, as well as reduce fruit quality (Calleja-Cervantes *et al.*, 2015; Pérez-Álvarez *et al.*, 2013).

Egypt has the natural resources to produce early-ripening grapes, the country's second-most important fruit crop after citrus in terms of acreage, production, and export (Abou-Zied and Abd El Latif, 2016). The harvested area (≈ 79000 ha.) produced ≈ 1.75 M tons (Egyptian Ministry of Agriculture Statistics, 2019). Egypt ranks in the 14th position worldwide (Abou-Zied and Abd El-Latif, 2016). Superior seedless grape is regarded as one of the most significant table grape crops, with fruits necessary for export to European markets (Ahmed and Hassan, 2020). Vineyard management involves a variety of agricultural processes that affect the soil's function. The most prevalent soil treatment practices in vineyards in arid regions are tillage and mechanical weeding; these leave the soil between the plants exposed all year round (Marín-Martínez *et al*., 2021). Irrigation is another essential management tool for enhancing and controlling grape output and quality, particularly in arid and semi-arid regions. In addition to altering the physical and biological characteristics of the soil and lowering its level of SOM (Salomé *et al*., 2016). Chen *et al*. (2023) stated that adding organic-inorganic fertilizers leads to an increase in the yield and quality of drip-irrigated grapes in an exceedingly arid region of Xinjiang, China. They found that combining organic and inorganic fertilizers can greatly improve the levels of available nitrogen, phosphorous, and potassium in soil. Muhammed *et al*. (2023) proposed that mixing chemical N fertilizers with organic amendments and bio-fertilizers can improve grape N availability and nutritional quality. This study aims to compare various nitrogen fertilizer sources applied with organic fertilizer on soil environmental quality attributes (SOM, nitrogen status, and some soil properties) and agronomic nitrogen availability measures (crop yield and quality) of a Flame seedless grapevine system in Middle Egypt. Thus, to diminish N-leaching, minimize fertilizer application, and improve grape quality, grapevine nitrogen application must be optimized for both the environment and the grower.

2. Materials and methods

The study was carried out during the successive seasons of 2021 and 2022 on selected uniform thirty-six flame seedless grapevines (18 years old and 2x3 m apart) grown in a private vineyard located at Tanda village, Malawy district, El-Minia Governorate (27°41'523" N latitude and 30°47'910" E longitude). The site has flat topography with good drainage, sandy clay loam texture, slightly alkaline pH, low organic matter, but appropriate potassium levels in the middle soil layers up to 60 cm depth. Table (1) shows some physical and chemical properties of the examined area as determined by Klute (1986) and Page *et al*. (1982). The chosen vines were pruned during the last week of December in both seasons. Spur pruning system using gable shape supporting methods was followed. The vine load for all the selected vines was adjusted to 72 eyes/ vine (on the basis of 15 fruiting spurs × four eyes plus six replacement spurs × two eyes). All vines received the same horticultural practices usually applied in the vineyard such as fertilization (each vine received 50 g of nitrogen), spraying Dormex, hoeing twice, irrigation, and punching as well as pest management. A surface irrigation system was practiced with a fresh source of Nile water.

Table (1): Some soil chemical and physical properties of the experimental site.

Soil depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture	SOM (%)	$CaCO_3$ (%)	EC_e (dS/m)	pH (1:1)	FC (%)	TN (%)
0-20	60	9.6	30.4	SCL	1.66	2.22	0.825	7.5	48.54	0.15
20-40	58.4	10.4	31.2	SCL	1.55	2.2	0.896	7.6	52.83	0.12
40-60	61.6	9.6	28.8	SCL	1.42	2.21	0.900	7.8	57.37	0.1

SOM = soil organic matter, EC = electrical conductivity, pH = soil reaction, FC = field capacity, TN = total nitrogen.

Each treatment contains two vines with three replicates, and they were arranged in randomized complete block design (RCBD). The details of treatments and application rates are provided in Table (2). All the selected vines were fertilized with nitrogen at a recommended dose of 50 g/vine/year. Ammonium sulphate as fast-release fertilizer (20.6 %N) was divided into three doses; the first (40% of the total amount) was added at the growth stage beginning (1st week of March), the second (40%) just after berry setting (at the middle of April), and the third (20%) after harvesting. The organic fertilizer (compost) that contains 1.5 % N was added once after winter pruning (last week of December) in digs 25 cm depth 25 cm far from the trunk of each vine and covered with soil. Enciabeen (as slow-release fertilizers) that contains 40.0% N was added once at growth stage beginning (1st week of March). The slow-release fertilizer was mixed with moist soil and added in digs 10 cm depth around the trunk of each vine (50 cm far from trunk); the digs were covered with moist soil and then they irrigated. Compost is made by leaving an aerial beam of a few medicinal and aromatic plants alone for two to three months. The chemical compositions of applied compost were performed according to Page *et al*. (1982) and they are shown in Table (3).

Table (2): Details of treatments and applying rates of N fertilizer from different mineral fertilizers and compost; an annual rate of N 50 g/vine is recommended.

Treatments	Ammonium sulphate 20.6 % N	Enciabeen 40.0 % N	Compost 1.5 % N
	g		
T_1 as 100% as fast-release (control)	242.0	-	-
T_2 N as 50% fast-release + slow-release 50%	121.0	62.5	-
T_3 as 100 % slow release	-	125.0	-
T_4 as 100 % compost	-	-	3334
T_5 N as 50% fast-release + 50 compost	121.0	-	1666
T_6 N as 50% slow-release + 50 % compost	-	62.5	1666

Table (3): Some chemical properties of added compost.

Property	Compost	Property	Compost
Cubic meter weight	600-700 kg	TK	0.8 %
Moisture	28.0%	C/N ratio	1: 14.5
OM	40%	T Fe	900.0 ppm
pH (1: 10)	8.0	T Zn	60.0 ppm
EC (dS/m)	4.5	T Mn	75.0 ppm
TN	1.5%	T Cu	130.0 ppm
TP	0.6%		

2.1 Soil sampling and analysis

Before and after each growing season disturbed and undisturbed soil samples were taken at depths of 0-20, 20-40, and 40-60 cm. In the laboratory, the samples were air-dried, ground, sieved (particle size < 2 mm), and prepared for physical and chemical analysis. Particles size distribution was carried out by the international pipette method as described by Klute (1986) using NH_4OH as a dispersing agent. Soil organic matter content was determined according to Baldock and Nelson (2000). Soil salinity and soluble ions were determined using the methods described by Page *et al.* (1982). Soil reaction (pH) was measured in (1:1) soil-water suspension using Beckman pH meter as reported by Page *et al.* (1982). Total and available nutrients were measured according to the methods described by Jackson *et al.* (1976). Campbell's (1994) core sampling approach was utilized to determine bulk density. Total porosity was calculated using the formula proposed by Brady and Weil (2008). Infiltration rate was measured using the double ring infiltrometer as described by Klute (1986). Hydraulic conductivity was measured by the auger hole method according to Amoozegar and Warrick (1986).

2.2 Samples of water drainage

Water samples from groundwater were collected through an observation well (PVC plastic pipe three inches in diameter and 60 cm in length that was inserted in a soil hole of 40 cm depth set aside 20 cm to prevent water runoff into the soil hole). The groundwater in the hole was sucked by a transparent plastic pipe (its diameter 10 mm and 70 cm length) embedded 10 cm into the groundwater surface in the hole after 24 h from irrigation. The groundwater samples were subjected to nitrate and ammonium analysis according to Jackson *et al.* (1976).

2.3 Vine yield, and fruit characters

The harvest was done when the total soluble soiled percent (TSS %) and acid ratio in the untreated berries reached 25: 1 in the second week of June during both seasons. During both seasons some vine yield and its quality were performed:

- Clusters number and their weight/ vine.
- Berry weight and dimensions (diameter and length).

- TSS (%) in the juice using handy refractometer.
- Reducing sugars (%) according to Lane and Eynon (1965).
- Total acidity as tartaric acid / 100 ml juice (Mohamed *et al*., 2020).

2.4 Statistical analysis

The data collected were subjected to a statistical analysis using Duncan's (1955). The significant differences among the means of various treatments were compared using Duncan's multiple range tests at a 5% level. Origin Lab has been utilized to carry out and present multivariate statistical analysis for principal component analysis (PCA).

3. Results

3.1 Weather conditions

Regarding grapevine, the daily mean temperature, humidity, and wind over the two experimental years did not match one another (Figure 1a) and followed the typical trend for that area. In the second year (2022), the air temperature during the summer season was less than in the first year, with low air temperature between January and August. As a result, throughout the two experimental years, the total reference evapotranspiration (ETo) values varied greatly (Figure 1b) which directly reflected the water plants need.

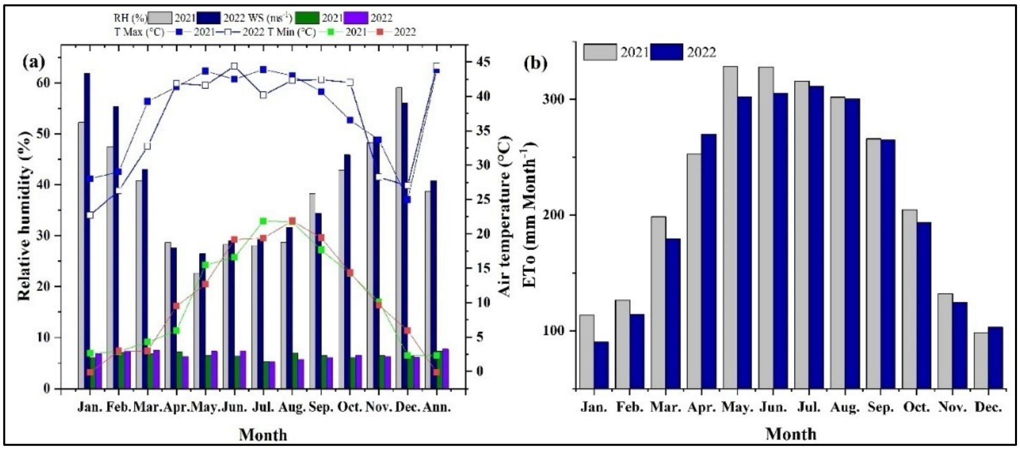

Figure (1): Monthly relative humidity (RH), wind speed, WS, (bars); maximum and minimum air temperature (line); (b) average reference evapotranspiration (ETo)during 2021 and 2022.

3.2 Soil bulk density (BD) and total porosity (TP)

Adding compost only or mixed with mineral fertilizers showed a reduction in soil bulk density (0-20 cm soil depth) compared to that of mineral treatments only (Figure 2). Each treatment of T4 (100% Compost), T5 (50% compost + 50% ammonia sulphate), and T6 (50%

compost + 50% Enciabeen) exhibited a reduction in soil bulk density and an increase in the total soil porosity compared to mineral treatments only.

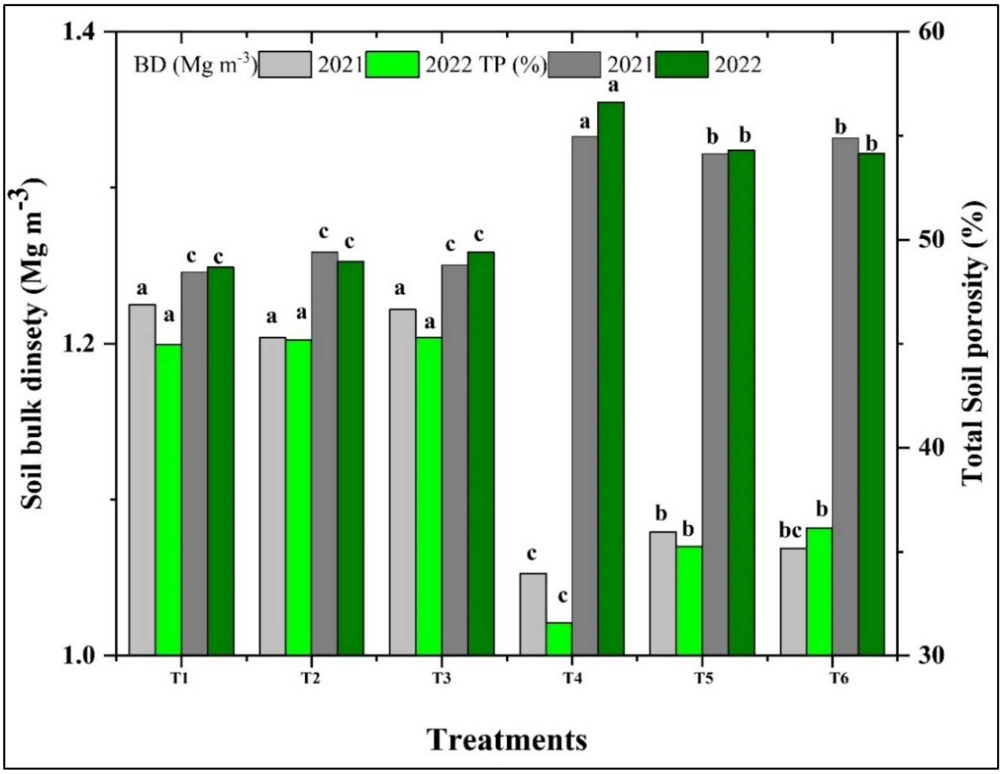

Figure (2): Impact of adding various nitrogen sources (either alone or mixed with compost) on soil bulk density (BD) and total porosity (TP). Lowercase letters indicate significant differences ($p<0.05$) between treatments.

3.3 Water mobility parameters

The capacity of soil for transmitting water under a hydraulic gradient is measured by saturated soil hydraulic conductivity (Ks). It is one of the important physical soil properties, especially in designing irrigation systems, as well as subsurface drainage systems. The Ks values as affected by different nitrogen fertilizer sources are shown in Table (4). Compost fertilizer, either applied individually or mixed with chemical fertilizer, generally led to higher soil Ks and infiltration rate (IR) values than those of chemical fertilizers only (Figure 3). The highest Ks value was observed in the T4 treatment, followed by the T6 and T5 treatments. The Ks values of T4, T5, and T6 treatments increased by 42, 16, and 17 %, respectively compared to the T1 treatment. Controlling groundwater levels, conserving soil and water, comprehending the physical properties, and solution movement in the soil matrix depend mainly on soil infiltration. The application of compost fertilizer, either individually or mixed with chemical fertilizers, led to an increase in the soil infiltration rate (IR) values in T4, T5, and T6 treatments by 21, 11, and 8% respectively, compared to the T1 treatment (Table 4).

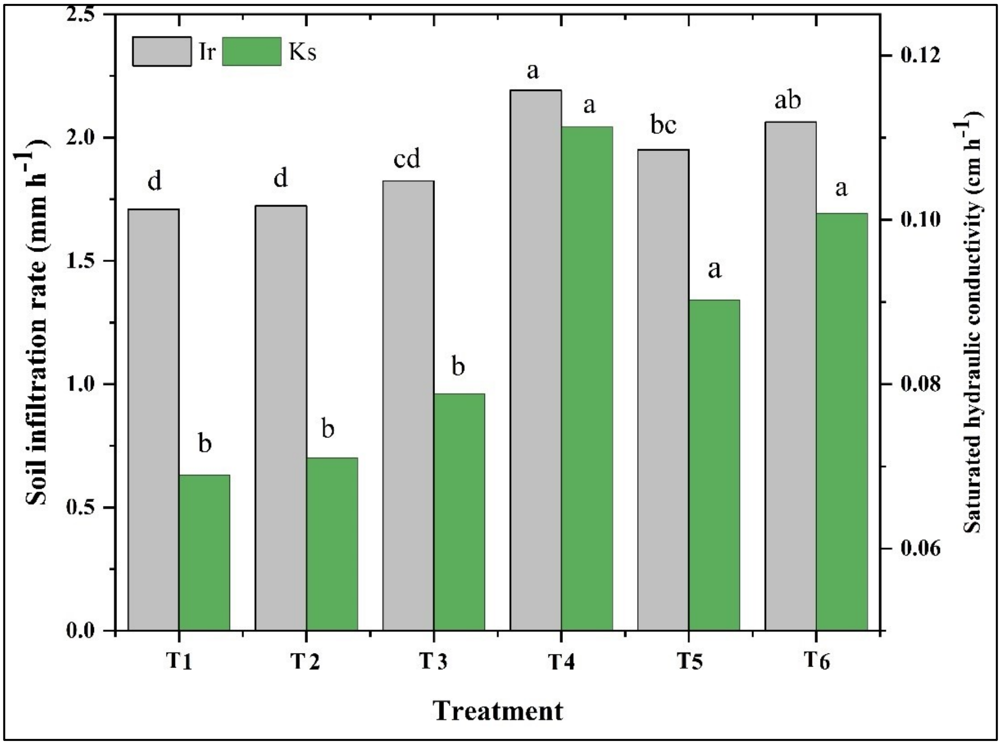

Figure (3): Impact of adding various nitrogen sources (either alone or mixed with compost) on saturated hydraulic conductivity (Ks) and soil infiltration rate (Ir) in both growing seasons of 2021 and 2022 (average of both seasons). Lowercase letters indicate significant differences ($p< 0.05$) between treatments.

3.4 Soil organic matter (SOM)

The effect of different nitrogen sources either individually or combined with compost during two seasons on soil organic matter content is presented in Table (4). SOM% was increased by the applications of compost and slow-release nitrogen fertilizer (Enciabeen) either alone or when combined with fast-release fertilizer (ammonia sulphate). In contrast, the treatment T4 (100% compost) demonstrated a highly significant increase in SOM% compared to the control (T1) and other treatments.

Table (4): Effect of adding compost only or mixed with various nitrogen fertilizers on saturated hydraulic conductivity (Ks), soil infiltration rate (Ir) and soil organic matter (SOM) during both growing seasons of 2021 and 2022.

Treatment	Ks (cm h^{-1})		Ir (mm h^{-1})		SOM (g kg^{-1})					
	2021	2022	2021	2022	2021			2022		
					Soil depth (cm)					
					0-20	20-40	40-60	0-20	20-40	40-60
T1	6.46×10^{-2}e	7.33×10^{-2}d	1.54d	1.88de	1.84f	1.75e	1.68e	1.84f	1.75e	1.68e
T2	6.73×10^{-2}de	7.47×10^{-2}d	1.62d	1.82e	1.87e	1.77de	1.72d	1.88e	1.76d	1.71d
T3	8.10×10^{-2}cd	7.66×10^{-2}d	1.72c	1.93d	1.90d	1.80d	1.73d	1.92d	1.78d	1.74c
T4	1.09×10^{-1}a	1.14×10^{-1}a	2.08a	2.30a	2.07a	2.05a	1.82a	2.13a	2.00a	1.82a
T5	8.74×10^{-2}bc	9.31×10^{-2}c	1.86b	2.04c	1.96c	1.86c	1.75c	1.97c	1.86c	1.75b
T6	9.75×10^{-2}ab	1.05×10^{-2}b	1.92b	2.21b	2.02b	1.97b	1.79b	2.07b	1.97b	1.81a
LSD 0.05	0.015	0.005	0.08	0.06	0.021	0.024	0.018	0.02	0.017	0.012

Different lowercase letters in the same column indicate significant differences at $p < 0.05$ according to Duncan's multiple range tests.

3.5 Available nitrogen

The effects of adding different nitrogen sources during both seasons on nitrogen availability are shown in Table (5). In general, nitrate and ammonium concentrations declined with soil depth, and nitrate is more readily available than ammonium. Also, the data showed that nitrate and ammonium concentrations in the second season were higher than those in the first season. The maximum nitrate concentrations were obtained with T4 treatment for both seasons. The data revealed that nitrate concentrations significantly increased by 27, 16, and 20% with T4 (100% compost), T5 (50% ammonium sulphate + 50% compost), and T6 (50% Enciabeen + 50% compost) treatments compared to T1 (100% ammonium sulphate) at surface soil layer. The opposite trend was observed at 40-60 cm soil depth by the end of 2021 and 2022 seasons indicating that the compost only or mixed with ammonium sulphate or Enciabeen led to decreased nitrogen leaching to deep soil layers.

Table (5): Effect of adding compost only or mixed with various nitrogen sources on nitrate and ammonium concentrations during both growing seasons of 2021 and 2022.

Treatment	0-20 cm				20-40 cm				40-60 cm			
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
	NO_3		NH_4		NO_3		NH_4		NO_3	NH_4		
T1	28.40e	30.97d	7.60d	8.47d	21.60e	22.40e	7.13e	8.13c	20.20c	21.47c	6.67d	7.07d
T2	32.00d	33.83c	9.27c	9.93d	24.87d	27.00d	9.00d	9.67b	23.20b	25.53b	8.34b	9.01b
T3	33.67c	35.67b	10.27c	12.47bc	25.87d	32.33bc	10.00c	11.80a	25.20a	27.20a	9.40a	10.20a
T4	36.62a	38.90a	13.00a	13.67a	33.80a	34.67a	11.87a	12.53a	16.20e	16.53e	6.47d	6.80d
T5	34.80b	34.00c	11.67b	11.87c	30.47c	31.40c	10.80b	10.20b	16.83e	17.33e	7.07cd	7.53dc
T6	35.13b	36.27b	12.27ab	12.60b	31.67b	32.93b	11.07b	12.13a	18.00d	19.00d	7.60bc	8.00c
LCD 0.05	0.71	0.83	0.62	0.56	0.69	0.67	0.52	0.62	0.78	0.8	0.59	0.5

Different lowercase letters in the same column indicate significant differences at $p < 0.05$ according to Duncan's multiple range tests.

3.6 Leaching of nitrogen

Figure (4) shows nitrogen concentration in groundwater of two successive seasons (2021 and 2022) in the forms of ammonium (NH_4) and nitrate (NO_3) as affected by applying various nitrogen sources alone or in combination with compost during different irrigation cycles. There were notable variations in the median of NO_3-N concentrations in groundwater among the tested treatments, ranging from 126 to 357 mg l^{-1}. When comparing the fast-release (T1) and slow-release (T3) or a combination of both (T2) treatments directly, total leaching losses consistently decreased when the fast-release fertilization was decreased. Nonetheless, the total N leaching losses in the treatments using compost as nitrogen fertilizer were 0.5–1 times fewer than those using chemical fertilization. The T5 treatment (50% compost + 50% ammonia sulphate) realized a high NO_3-N concentration which was not supported by lower values recorded in other treatments (T4 and T6). The leached amounts of nitrogen in the form of NO_3^- are much higher than those in the form of NH_4. The NH_4-N concentration values in groundwater show graduate decline slowly through consequent irrigation cycles, and they ranged between 13 and 67 mg l^{-1}.

3.7 Grapevine yield and characteristics of the clusters

The yield/vine, cluster weight, berry weight, and berry dimensions of Flame Seedless grapevines in 2021 and 2022 seasons were significantly affected by compost and various nitrogen fertilization sources (Table 6). The yield/vine, cluster weight, number/vine, berry weight, and dimensions were significantly increased in T2 treatment (50% ammonium sulphate + 50% Enciabeen) and T5 treatment (50% compost + 50% ammonium sulphate) compared to other treatments (Table 6). Flame seedless grapevines at T2 treatment realized an economical yield. Under such promising treatment, production per vine was 13.00 and 17.85 kg in the 1st and 2nd seasons, respectively. Adding 100% Enciabeen (T3) produced the lowest yield (11.05 kg) in the first season. The same trend was noticed in the 2nd season when adding 100% compost (T4 treatment) which produced the lowest yield (11.90 kg).

3.8 Some physical and chemical characteristics of berries

Berry properties as affected by various nitrogen treatments through 2021 and 2022 seasons are shown in Table (7). The results showed that applying a combined form of fertilization greatly enhanced the quality of the Flame Seedless grapes (increase in total soluble solids, TSS, berry coloration and reducing in both sugars and total acidity) compared to control treatment (100% ammonium sulfate). During both seasons, flame seedless grapevines in T2 treatment (50% Enciabeen + 50% ammonium sulphate) and T5 treatment (50% ammonium sulphate + 50% compost) were considerably superior to that of T1 (100% ammonium sulphate) or T4 (100% compost). This treatment (T2) caused increases in TSS %, berry weight and dimensions, TSS/acid and total sugars % but decreased total acidity percentage in the berries (Table 7).

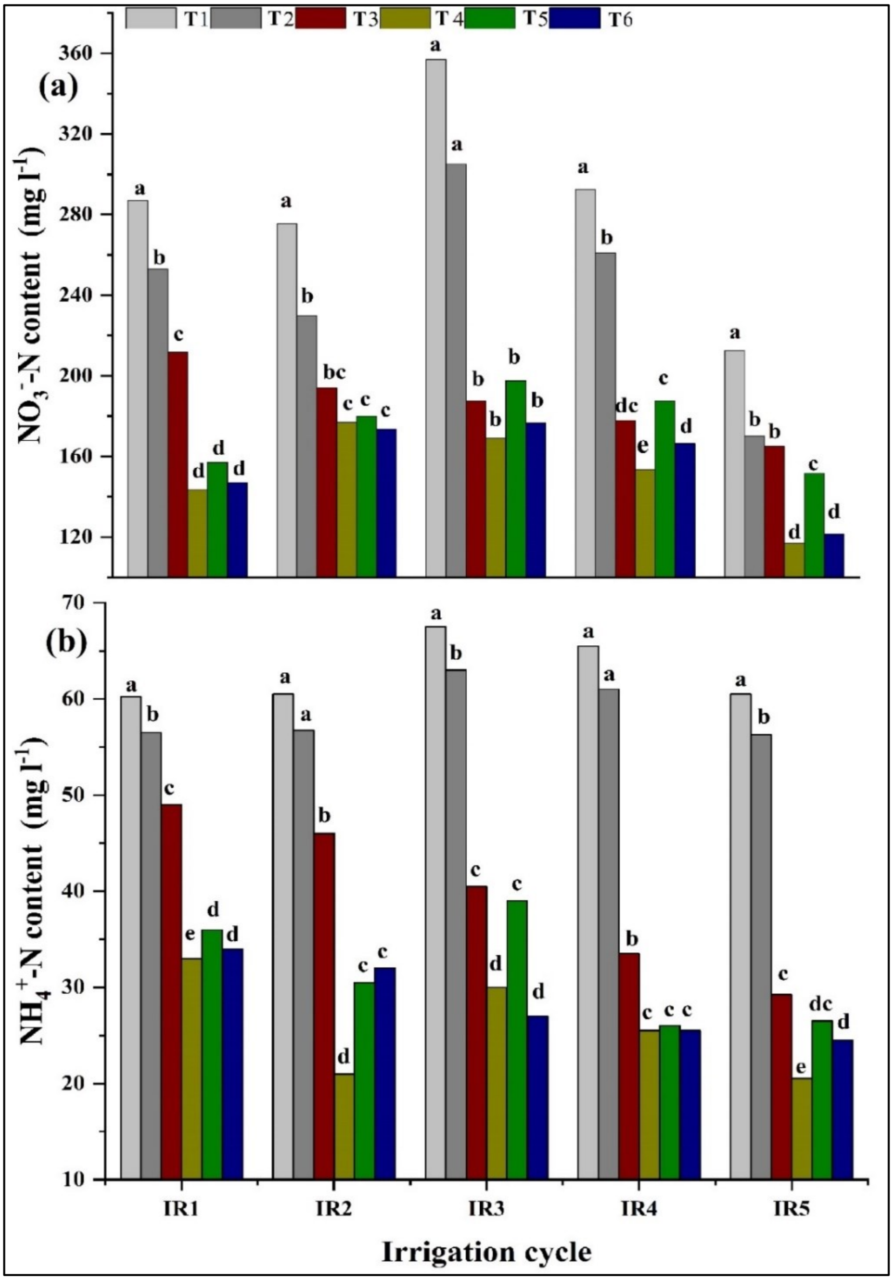

Figure (4): Effect of adding various nitrogen sources alone or mixed with compost on NO_3-N and NH_4-N concentration in drainage water during both growing seasons of 2021 and 2022 (average of both seasons). Lowercase letters indicate significant differences ($p<0.05$) between treatments.

Table (6): Effect of adding various nitrogen sources alone or mixed with compost on yield, clusters number/ vine, cluster weight, berry weight, and dimensions of Flame seedless grapevines during both growing seasons of 2021 and 2022.

Treatment	Clusters (No./vine)		Cluster weight (g)		Yield/vine (kg)		Berry weight (g)		Berry longitudinal (cm)		Berry equatorial (cm)	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
T1	26.0a	29.0c	425.0c	433bc	11.05c	12.47d	2.31c	2.35c	2.35b	2.38bc	2.08bc	2.12cd
T2	26.0a	35.0a	500.0a	510a	13.00a	17.85a	2.90a	2.95a	2.60a	2.63a	2.50a	2.56a
T3	26.0a	28.0c	420.0c	430bc	11.25c	12.04e	2.25cd	2.30c	2.32b	2.36c	2.02c	2.06cd
T4	27.0a	28.0c	415.0c	425c	11.21c	11.90e	2.22d	2.26c	2.30b	2.33c	1.99c	2.03d
T5	26.0a	35.0a	490.0a	502a	12.74ab	17.50b	2.83a	2.86a	2.55a	2.56a	2.40a	2.44ab
T6	26.0a	31.0b	450.0b	460b	11.70bc	14.26c	2.45b	2.49b	2.42b	2.45b	2.20b	2.25bc
LSD 0.05	NS	1.62	15.40	30.9	0.44	1.11	0.08	0.11	0.12	0.074	0.15	0.18

Different lowercase letters in the same column indicate significant differences at $p < 0.05$ according to Duncan's multiple range tests.

Table (7): Effect of adding compost only or mixed with various nitrogen sources on berry coloration, and some chemical parameters of the berry of Flame seedless grapevines during both growing seasons of 2021 and 2022.

Fertilizer treatment	Berry coloration (%)		TSS (%)		Total acidity (%)		Reducing sugars (%)		TSS/acidity	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
T1	76.00d	77.10d	18.1c	18.3bc	0.600b	0.590a	15.8d	16.0a	30.2c	31.0d
T2	90.00a	91.00a	21.0a	21.2a	0.475d	0.470c	19.7a	20.0a	.44.2a	45.1a
T3	75.00de	76.10de	17.8c	18.0c	0.615ab	0.610a	15.5de	15.8a	28.9cd	29.5e
T4	74.20e	75.50e	17.7c	17.9c	0.625a	0.615a	15.3e	15.6a	28.3d	29.1e
T5	87.00b	88.40b	20.8a	21.0a	0.480d	0.475c	18.5b	18.8a	43.3a	44.2b
T6	80.23c	81.30c	19.1b	19.4b	0.520c	0.515b	16.9c	17.2a	36.7b	37.6c
LSD 0.05	1.38	1.05	0.69	1.25	0.02	0.03	0.42	NS	1.37	0.83

Different lowercase letters in the same column indicate significant differences at $p < 0.05$ according to Duncan's multiple range tests.

3.9 Multivariate analysis

Principal component analysis (PCA) was used to assess the effects of applying various nitrogen sources either alone or in combination with compost on soil properties, available N, nitrogen leaching, and flame seedless grapevine production (Figure 5a,b). For both seasons, the first two axes were significant, accounting for 93.7 and 90.5% of the total variation, respectively. As shown by the clustering in Figure 5a and b, the compost treatments (T4, T5, and T6) were strongly correlated with SOM, available nitrogen; and water movement; these clusters were explained primarily by the high positive relation of PC1 in the first season and PC2 in the second season. On the other hand, the clustering shows that the mineral N treatments (T1, T2, and T3) were strongly correlated with nitrate or ammonium leaching and soil compactions indicator (soil bulk density); these clusters were explained primarily by the high negative relation of PC1 in the first season and high positive relation of PC1 in the second season. This displays how adding compost, individually or mixed with other nitrogen sources, significantly improves soil features, available nitrogen and nitrogen loss control. PC2 components are mostly connected to crop yield and TSS. As shown by the clustering in Figure (5a, b) T2 (50% ammonium sulphate + 50% Enciabeen) and T5 (50% ammonium sulphate + 50% compost) treatments were strongly correlated with Flame seedless grapevine yield; these clusters were explained primarily by the high positive relation of PC2 in both seasons. Individual fertilizer treatments and total acidity showed a substantial correlation, which can be mainly attributed to the high positive relation of PC2 in both seasons. This highlights the significance of organic matter and available N, which are the primary factors influencing grapevine productivity.

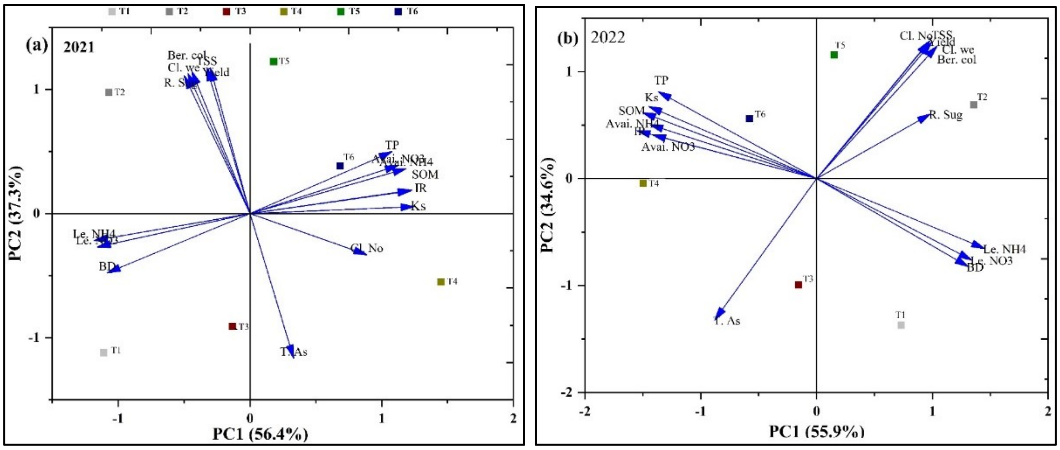

Figure (5): Multivariate analysis (PCA) of the impact of adding compost only or mixed with various nitrogen sources on soil bulk density (BD), total porosity (TP), saturated hydraulic conductivity (KS), soil infiltration rate (Ir), available nitrate (ava. NO_3), available ammonium (ava. NH_4), leaching nitrate (Le. NO_3), leaching ammonium (Le. NH_4), yield, cluster weight (Cl. We), number (Cl. No), berry coloration (Br. col), total soluble solids (TSS), reducing sugars (RS), and total acidity (T. As). a) for the 2021 season, and b) for the 2022 season.

4. Discussion

The bulk density reduction and the increase in total soil porosity (Figure 2) revealed that adding compost caused an increase in the soil organic carbon (SOC). Furthermore, the plant residue and added compost on soil surface may cause a low in BD values of the soil surface. However, SOC has the most significant impact on bulk density because it improves bioactivity and root penetration, both of which lower soil bulk density (Bandyopadhyay *et al*., 2010; Bogunovic *et al*., 2023). According to Bogunovic *et al*. (2023), soil organic carbon played a significant role in both enhanced soil total porosity and decreased BD. Adding compost to agricultural areas is a dependable method of enhancing most soils physical properties, particularly those with low levels of organic matter and poor structure. Those beneficial impacts are interactive and are related to the materials of used compost and the amount of OM in the feedstock (krazen *et* *al*., 2020). Saturated hydraulic conductivity (Table 4) and soil infiltration rate were strongly correlated with reduced bulk density, increased soil organic carbon content, and stable soil structure. Abdelrhman *et al*. (2021) showed that the formation of stable macroaggregates (0.25-0.053 mm) and the cohesion of mineral soil particles due to increasing the SOC content create soil aggregates that provide good soil hydraulic properties. These results are consistent with those of Al-Suhaibani *et al*. (2020), Dong *et al*. (2022), Liao *et al*. (2023), and Meena *et al*. (2020). Dong *et al*. (2022) hypothesized that the enhancement of the soil structure and hydraulic properties by fertilizer application is evidenced by a reduction in BD and a rise in SOC and IR of the soil under arid regions. In comparison to untreated control plots, Rayne and Aula (2020) found that continuous application of both organic and inorganic fertilizers significantly increased the rate of soil infiltration. In arid and semi-arid soils, deep roots of grapevines can enhance hydraulic conductivity by forming root channels, fissures, and secretions that promote aggregate formation. In terms of structural variables on Ks, Bandyopadhyay *et al*. (2010) found that carbon (C) quantity and BD were the most significant. Meena *et al*. (2020) reported that organic amendments decreased soil bulk density, raised infiltration rates, and reduced water erosion in semi-arid soils. The increase in SOC from the organic material applications most likely raises the root growth, biological activity, and pore space of the soil leading to a rise in the water infiltration rate (Crittenden *et al*., 2015; Hu *et al*., 2018; Xin *et al*., 2016). The most significant factor influencing soil fertility, soil development, soil biology, and physical and chemical soil attributes, all of which have an impact on crop productivity, is soil organic matter (SOM) (Gerke, 2022). Our results clearly showed that compost treatments with or without mineral fertilizers increased soil organic matter over mineral fertilizer only. Also, it is noticed that soil organic matter increased by increasing Enciabeen to Ammonium sulphate addition and this increase was more pronounced at T3 treatment (100% Enciabeen). This could be due to Enciabeen has high accessible nitrogen content and longer time after fertilization that enhanced microbial and fungal activity (Geng *et al*., 2017). Additionally, by reintroducing crop waste into the soil, mineral fertilizer may raise the SOM concentration. In the meantime, the amount of SOM decreases because of C mineralization. Consequently, the contents of SOM preserve soil in a dynamic equilibrium. In this study, mineral fertilizer application had no significant influence on SOM content (Mirzavand and Moradi-Talebbeigi, 2021). The SOM contents of the studied topsoil significantly increased by compost application (Table 4). In addition, compost application combined with mineral fertilizers played a main role in the increase of SOM. The integrated applications of organic material and mineral fertilizers had better promise for both recovering and increasing SOC (Chen *et al*., 2023). Al-Suhaibani *et al*. (2020) reported that the integrated use of organic materials along with 50% of the recommended dose of minerals fertilizer or high application rate of manure only significantly increased SOM and soil microbial biomass carbon compared to applying the full recommended dose of minerals fertilizer. Available nitrogen is thought to be a crucial element impacting nitrogen leaching and NH_3 volatilizing (Vogeler *et al*., 2021). Nitrogen loss rose as more available N, and NH_3 volatilization showed a substantial positive association with available N. Minimizing the loss of excessive N to the environment is required to improve nitrogen use efficiency and a safe environment. Plants take most of their nitrogen from NO_3-N and NH_4-N. But they rapidly drain out of the plant root zone, which has historically been the primary source of loss in grape orchards. The increases in NO_3-N and NH_4-N content were declared with increasing rates of Enciabeen and ammonium sulphate at all soil layers. Applying ammonium sulphate to the soil causes it to be quickly dissolved by urease, which raises the pH of the soil, increases the amount of accessible N, and ultimately causes a significant loss of N (Tripolskaja and Verbylienė, 2014). A slow release with an extended-release period, N fertilizer reduced its release to best suitable the needs of plants at different phases of growth and, as a result, decreased N loss (Guo *et al*., 2021). Our results support these findings since T2 and T3 treatments increased available N at the end of grapevine season compared to T1 treatment. The increases in nitrogen availability were more declared with the combined applications of mineral and compost treatments than the recommended dose of ammonium sulphate or Enciabeen treatments only at surface soil layer (0-20 cm). By season's end in 2021 and 2022, the reverse pattern was noticed at 40-60 cm soil depth, suggesting that compost mixed with urea or ammonium sulphate reduced N leaching to deep soil layers. In this case, a combination of N had been able to meet the crop's requirements, leaving more nutrients in the topsoil to provide nutrition to the plants and prevent long-term nitrogen leaching. These results agree with those of Murugan and Swarnam (2013) who reported that adding manures (vermi-compost and poultry) and chemical fertilizers (urea) to the soil significantly increased the concentration of available nitrogen due to net mineralization during the decomposition. Mengistu *et al*. (2017) mentioned that the highest soil nitrogen was recorded on plots receiving 75% recommended dose of chemical fertilizer and 25% vermicompost. Also, it observed that the NH_4-N content was low in all treatments, which is usual in arid areas where the mineralization and nitrification rates are high. The NH_4-N contents were high in the compost treatments and slow-release fertilizer treatments, probably due to the lower degree of stabilization of this organic amendment and Enciabeen, favoring the mineralization of organic N.

The content of NO_3^- has significantly grown due to anthropogenic activity, especially in the water table (Chand *et al.*, 2011). Most of the major risks of contamination of the water table are known to be nitrate leaching from nonpoint cultivation resources, such as chemical fertilizers usage (Orellana-Macías *et al.*, 2021). Due to the possibility of environmental harm as well as health risks, elevated NO_3^- in water might result in ecological concerns caused by leaching from the rhizosphere area. More than acceptable levels of 10 mg l^{-1} for NO_3^- may result in methemoglobinemia, cancer of the stomach, miscarriage, and lymphoma (Ward *et al.*, 2005). Guo *et al.* (2021) found that while slow release showed higher NO_3 in the 0–40 cm soil layer, it decreased the overall amount of NO_3 leaching in the soil when compared to fast release. According to Zheng *et al.* (2016) plant roots were mostly localized in the 0-40 cm soil layer. As a result, overly NO_3 under the 40 cm soil depth raised the danger of ecological contamination and impaired the effectiveness of nitrogen usage. This study shows that by balancing the soil N supplies and crop N uptake, simultaneous applications of slow-to-fast release have a significant ability to reduce N leaching (Tian *et al.*, 2021). The best results on sustainable grapevine productivity were obtained with treatment T2 (50% Enciabeen and 50% ammonium sulphate), which reduced N leaching and increased crop yield. Furthermore, according to Guo *et al.* (2021) crop yields were raised, and the N balance was preserved when the slow-to-fast release ratio was appropriate. When comparing the application of mineral N to organic N application, the low values of organic materials highlighted the general reduction possibility of nitrate concentration in leachate. As a result, there is less chance of groundwater pollution. The probability of water-table pollution could be determined through the mineralization rate of the organic N. Perin *et al.* (2020) demonstrated that compost could be used as an organic fertilizer to partially replace mineral fertilizers without posing a major nitrate leaching risk. The present data showed a high NO_3^- -N concentration in groundwater in the first irrigation cycle in all treatments. This may be due to the winter treatment and residual effect of the last dose of ammonium sulphate. In the same direction through irrigation cycle No. 3 at treatments containing ammonium sulphate, NO_3-N concentration increases in groundwater to reach a value of 350 ppm in T1 (100 ammonia sulphate) treatment. This is a result of adding the second dose of nitrogen fertilization. According to Guo *et al.* (2022) nitrogen losses rose with each fertilizer and irrigation application. Most of the volatilization loss happened within two weeks of the N treatment and then declined until the next N fertilizer application. The small amounts of nitrogen in the form of NH_4^+ which were detected in groundwater may be explained based on the fast changes of NH_4 form to NO_3 form. Ammonium ions (NH_4^+) that are not stabilized or rapidly absorbed by plants are often transformed into NO_3 ions through an operation known as nitrification. That is a two-step operation where Nitrosomonas bacteria transform NH_4 to nitrite (NO_2), followed by Nitrobacter bacteria, which transform the NO_2 to NO_3. Good-aerated soil is necessary for this operation, which encourages more NO_3 than NH_4 formation through the growing season (Zhaohui *et al.*, 2012). Additionally, the climate and soil of Middle Egypt are conducive to the nitrification and mineralization processes. According to Guo *et al.* (2021) there is a substantial correlation between the concentration of NH_4-N and the N loss rate. The N loss rate is influenced by physical and chemical features of soil, climate, and management practices. The prior beneficial effect of organic materials on both the development and fruiting of flame seedless grapevines may be identified mostly as the vital role of organic fertilizers. Furthermore, these organic fertilizers are believed to improve nutrient absorption, photosynthesis, stabilization of nitrogen, retention of water, vitamin B complex, ability of most nutrients, soil flexibility, and resilience against drought (Abd EL-Rahman *et al.*, 2021). The reason why trees develop N insufficiency at reduced nitrogen rates might be attributed to the slow-releasing properties of compost and the significant solubility of mineral nitrogen (Mengel *et al.*, 2001). The effect of slow-release N fertilizers on fruiting weight may be explained by the constant release of N throughout all growth phases, particularly during the fruit development stage. It is also necessary to consider the significant promoting role of nitrogen in cell division, cell elongation, and the production of proteins and carbohydrates. To achieve an ideal equilibrium between growing and producing fruit, slow-release nitrogen fertilizers have the ability to adjust the release of nitrogen, which was evident in the buildup of total carbohydrates and their availability to enhance fruit ripening (Guo *et al.*, 2022). The current results showing the beneficial effects of slow-release fertilizer and organic application on growth, vine nutritional status and fruiting and they are in an accordance with those obtained by Ahmed *et al.* (2017), El-Salhy *et al.* (2017), Ahmed and Hassan (2020), and Guo *et al.* (2021; 2022). Both fruiting and berry quality aspects were improved in response to organic and slow-release fertilizer compared to fast-release fertilization only, as previously reported by Abd El-Rahman *et al.* (2021) who found that mineral nitrogen fertilization plus humic acid or compost and bio-mix increased yield/vine and cluster weight while decreasing cluster compactness coefficient compared to applying N as 100% mineral fertilization. Also, they found that applying a double or triple fertilization strategy considerably improved the quality of Flame Seedless grapes by increasing total soluble solids, decreasing sugar and anthocyanin levels, and decreasing overall acidity compared to the control treatment (100% mineral N). Muhammed *et al.* (2023) concluded that organic and bio-fertilization had a beneficial impact on growth, vine nutrition status, number of clusters per vine, berry setting (%), and cluster weight. Also, they revealed that application of 60 and 40% of the required nitrogen dose as mineral nitrogen combined with organic amendments and bio-fertilizers to superior grapevines resulted in significantly higher TSS and lower acidity percentages.

5. Conclusion

The present study assessed the effects of various mineral and organic nitrogen sources applied individually or in combination on the amount of available nitrogen, certain physical characteristics of the soil, grapevine productivity, and the amount of nitrogen leaching in arid vineyard agricultural conditions. It might conclude that adding compost to agricultural areas enhanced most soil physical and hydraulic properties particularly those with low levels of organic matter and poor structure. The best way to improve the soil properties, grape yield, and chemical characteristics of seedless grapevines, and ultimately reduce N loss is to apply both slow-release and fast-release fertilizers; or to combine mineral fertilizers and organic materials. Using fast-release nitrogen fertilizers alone increases nitrogen leaching, decreases yields, and raises the danger of water contamination. Diminishing the loss of excessive nitrogen to the environment is required to improve nitrogen use efficiency and create a safe environment. In general, the study suggests that the application of organic fertilizers derived from plant waste combined with mineral fertilizers can enhance soil properties and regulate N leaching, thereby reducing the environmental impact on the agricultural production sector in arid regions. As a result, the application of organic fertilizers should be studied more thoroughly and promoted as part of the sustainable development of the agricultural sector, particularly in arid countries highly susceptible to global and regional environmental degradation.

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