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Original Article

Nitrogen management in a sandy loam soil grown with cucumber plants and fertilized by vermicompost

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Abstract

Global attention is shifting to using fertilizers organically produced from available wastes in the surrounding ecosystem to provide sustainability in agriculture and conserve the environment. The aim of this study is to investigate the possible changes in the yield and quality of cucumber resulting from different combinations of organic solid and liquid fertilizers prepared from different organic wastes, as compared to applying mineral fertilizers. Furthermore, detecting available N concentration in sandy loam soil and total N concentration in cucumber leaves considering the effect of the studied treatments every 15 days after transplanting (DAT) until 120 DAT. Four fertilizer treatments (3 organic fertilizers, i.e., vermicompost (VC), pigeon manure (PM), and compost (COMP) in addition to mineral fertilizers) were tested in a randomized complete blocks design with three replicates. The organic fertilizer treatments were divided into three categories, the first was solid added through two equal doses. The second category was like the first one plus adding vermicompost tea (VCT) through drip irrigation (DI). The third category was like the second one, but the VCT was substituted with pigeon manure tea (PMT). Obtained results showed that the treatments of $PM_{50/50}$, and $VC_{50/50}$ as ground applications plus PMT or VCT through DI were given significant increases in available N in the studied soil, and enhanced the cucumber plant growth parameters, yield traits, and the total concentration of N in leaves throughout the experimental period. Additionally, the highest benefit/cost ratio (5.68) was achieved with the application of organic treatments compared to traditional ones (3.28).

Keywords: Vermicompost, Pigeon manure, Organic aqueous extract, Organic farming, Detecting N in soil and plant, Cucumber plants

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Introduction

Agricultural growth because of the increasing population has led to increased soil cultivation many times per year; this causes a depletion in soil fertility. However, nutrient losses in the soil have been replenished by applying mineral fertilizers which have many disadvantages, like their high economic costs and harmful effects on human health and the environment (Abd-Elrahman, 2017). Therefore, global attention is shifting to using fertilizers organically produced from wastes available in the surrounding ecosystem (Elgala et al., 2022; Nossier et al., 2022). Hence, using vermicompost in soil enrichment has received general interest (Abd El-Fattah et al., 2022). Many researchers have reported that vermicompost offers an affordable and readily available solution (Esmaielpour et al., 2020; Malo et al., 2022) and is an important source of macro- and micronutrients (Thongney et al., 2018). Aside from being a source of essential nutrients for plants, soil's physical and biological properties are also enhanced (Abdrabbo et al., 2015). Moreover, it is a good source of natural plant growth regulators like cytokinin and auxins. It also contains large amounts of humic substances, revealing considerable impacts on plant performance (Hashem and Abd-Elrahman, 2016). In addition, the use of vermicompost can decrease the problem of excess nitrate in soil and growing plants (Abd-Elrahman et al., 2022b). Also, compost as an organic fertilizer is a valuable material that enriches soil properties, by enhancing aeration, water holding capacity, organic matter content, nutrient availability, and reducing soil bulk density (Hashem and Abd-Elrahman, 2016). Moreover, the application of pigeon manure for soil biofertilization and restoration has highly received attention as eco–friendly and low–cost fertilizer (Salem et al., 2018).

The application of an aqueous extract of vermicompost (vermicompost tea) has been shown to improve the physio-biochemical properties of soils. In addition, it improves seed germination, plant growth and development, crop yield, and nutritive quality (Hashem and Abd-Elrahman, 2016). Also, pigeon manure tea was used as liquid organic fertilizer and showed an increase of soil available NPK led to enhanced seedling development, giving vigor to plant growth, helping plants to face abiotic stresses and bad weather, and controlling some diseases (Haggag et al., 2015; Salem et al., 2018).

Cucumber (*Cucumis sativus* L.) is an annual vegetable belonging to the family Cucurbitaceae. It is grown for its edible tender fruits that are used for pickles and salad. Cucumbers give humans several health benefits such as preventing dehydration, lowering blood sugar and pressure, avoiding kidney stones, and aiding in weight loss (Mohan et al., 2016). Cucumbers may play a role in controlling and preventing diabetes due to their antioxidant content that helps to remove free radical substances from the human body. It is also very effective in preventing constipation and indigestion (Malo et al., 2022). Therefore, it is necessary to direct the research towards efficient utilization of available nutrient resources to increase productivity and profitability per unit area to meet the food demands of the ever-increasing population. Applying organic fertilizers increases cucumber production and its vitamin C and protein content while decreasing nitrate accumulation in cucumber fruit compared to applying mineral fertilizers (Thongney et al., 2018; Esmaielpour et al., 2020).

Recycling agricultural wastes would be less costly and consistent with the organic approach to soil fertility, which emphasizes rotation with leguminous cover crops, growing green manure crops, and application of compost or different types of manure or organic materials. In addition, determining which organic material is suitable to apply, how much, and when to apply is just as important in organic agriculture and supplying soil and growing plants with essential nutrients such as N. Thus, the aims of this study are to (1) study the effect of different combinations of organic solid and liquid fertilizers as well as mineral fertilizers on soil available N with time, in addition to the quality and yield of grown cucumber plants. (2) Detecting N concentration in cucumber leaves considering the effect of the studied treatments. Furthermore, (3) studying the profitability of applying organic fertilizers compared to applying traditional ones (farmer's practice) as a control treatment.

Material and Methods

The experimental site

An experiment was carried out in the autumn of 2021 under greenhouse conditions at Abu-Ghalib farm (30.2102847 N, 30.7251743 E), Cairo-Alexandria desert road, Giza governorate, Egypt. The standard methods outlined by Klute (1986) and Page et al. (1982) detected that the soil is sandy loam and some initial physical, chemical, and biological properties of the experimental soil (0-30 cm) are presented in Table 1.

Table-1. Properties of soil (0-30 cm depth) before cultivation.

Property	Unit	Value
Physical properties		
Sand	%	70.5
Silt	%	29.3
Clay	%	0.20
Textural class		Sandy loam
Saturation percent	%	21.0
Chemical analysis		
Acidity pH (1:2.5 soil: water suspension)	unitless	8.31
Electrical conductivity of soil extract (EC_e)	dS m^{-1}	4.42
Calcium carbonate	%	7.55
Organic matter	%	1.03
Organic carbon	%	0.60
Total nitrogen	%	0.05
C/N ratio		12.0
Available nutrients	µg g^{-1}	
Nitrogen		53.0
Phosphorus		6.22
Potassium		161
Iron		0.78
Manganese		0.23
Zinc		0.14
Copper		0.04
Soluble ions	meq L^{-1}	
Calcium		15.5
Magnesium		10.5
Sodium		27.0
Potassium		1.25
Bicarbonate		2.50
Chloride		34.5
Sulfate		17.2
Biological analysis		
Pathogenic nematode	Larvae per 5 g soil	Not infected with eggs or larvae
Carbonate ions were not detected.		

Plant material and design

Seeds of cucumber (*Cucumis sativus* L. var. Barchouda F1) were sown on 23rd October 2021, in polystyrene trays. After 15 days from sowing, cucumber seedlings were cultivated under greenhouse conditions (date of cultivation: 7th November 2021), 50 cm apart on both sides of the ridge. In a randomized complete blocks design with 3 replications, 4 fertilizer treatments (3 organic fertilizers, i.e., vermicompost, pigeon manure, and compost in addition to mineral fertilizers) were tested. The organic fertilizer treatments were divided into 3 categories, the first was solid added through 2 equal doses; the first one was added during soil preparation before one week of plant cultivation and the second one was added after 30 days from transplanting. The second category was like the first one plus adding vermicompost tea through drip irrigation (DI) once a week starting from 23 days after transplanting (DAT) to 105 DAT. The third category was like the second one but the vermicompost tea was substituted with pigeon manure tea at the same periods of addition. The studied treatments were as follows:

1- $VC_{50/50}$ + VCT	6- $COMP_{50/50}$ + PMT
2- $PM_{50/50}$ + VCT	7- $VC_{50/50}$
3- $COMP_{50/50}$ + VCT	8- $PM_{50/50}$
4- $VC_{50/50}$ + PMT	9- $COMP_{50/50}$
5- $PM_{50/50}$ + PMT	10- Farmer practice (Control)

Table-2. Chemical composition of the used well water for irrigation.

Property	Unit	Value
Acidity pH	unitless	8.06
Electrical conductivity of water (EC_w)	dS m^{-1}	2.90
Total soluble salts (TSS)	mg L^{-1}	1856
Soluble ions	meq L^{-1}	
Calcium		9.85
Magnesium		8.12
Sodium		10.7
Potassium		0.32
Bicarbonate		3.30
Chloride		15.4
Sulfate		10.3
Ammonium	mg L^{-1}	3.50
Nitrate	mg L^{-1}	< 1.00
Phosphate	mg L^{-1}	0.01
Iron	mg L^{-1}	0.18
Manganese	mg L^{-1}	0.08
Zinc	mg L^{-1}	0.05
Copper	mg L^{-1}	0.02
Boron	mg L^{-1}	0.02
Carbonate ions were not detected. According to Ayers and Westcott (1989), the classification of irrigation water was low.		

The net experimental plot area was 6.0 m x 30.0 m (180 m^2), involving five ridges, 38 m length and 1.0 m width. A drip irrigation system was set up with 50.0 cm dripper spacing, and manufacturing dripper discharge 4.0 L h^{-1}, at an operating pressure of 1.0 bar. Cucumber plants were irrigated daily for 30 min divided equally in the morning and in the evening using well water for irrigation. The total amount of applied water for irrigation was 1650 m^3 $acre^{-1}$ (14 L $plant^{-1}$ $week^{-1}$) during the studied season. Some chemical properties of the used water for irrigation are presented in Table 2.

Table-3. Some physical, chemical, and biological properties of the used fertilizers in the experiment.

Property	**Rabbit manure**	**Chicken manure**	**Pigeon manure**	**Compost**
Color	Black	Brown	Black	Black
Weight of 1 m^3 (kg)	320	450	400	600
Moisture content (%)	19.0	6.00	18.0	17.0
pH (1:10 organic material: water suspension)	6.70	8.52	6.30	7.20
EC_e (dS m^{-1})	5.83	5.49	3.84	8.90
Total N (%)	2.34	3.34	2.70	0.90
Organic matter (%)	71.9	56.0	50.3	26.0
Organic carbon (%)	41.7	32.5	29.2	15.1
Ash (%)	28.1	44.0	30.5	74.0
C/N ratio	17.8	9.72	10.8	16.8
Total P (%) as P_2O_5	2.01	1.79	1.64	0.75
Total K (%) as K_2O	1.20	0.97	2.15	0.78
Humic acid (%)	0.20	0.98	0.34	0.45
Fulvic acid (%)	0.16	0.25	0.81	0.34
Weed seeds germination (%)	nil	nil	nil	nil
Pathogenic nematode (Larvae per 200 g soil)	Not infected	Not infected	Not infected	Not infected
Pathogenic fungi spp. *Fusarium, Rhizoctonia, Pythium, Phytophthora, Alternaria, and Verticillium*	Not infected	Not infected	Not infected	Not infected
Biological N_2- fixers (CFU mL^{-1})				
Azospirillum spp.	5.2×10^4	50.0×10^4	6.3×10^4	3.5×10^4
Azotobacter spp.	2.8×10^4	40.4×10^4	3.4×10^4	nil
Plant growth regulators (PGRs)				
Gibberellic acid (µg g^{-1})	n.d.	368	433	n.d.
Cytokinin (µg g^{-1})	n.d.	215	262	n.d.
Total amino acids (µg g^{-1})	n.d.	79.0	50.0	n.d.
n.d. means not detected.				

The studied treatments

An outdoor vermicompost system was established in September 2021 in a ground basin 4 x 2 x 0.4 m^3. The basin was covered with a plastic sheet that had 10 drainage holes (2 x 2 cm²) to facilitate effective water drainage. The cultural bed is structured from 4 layers. The first one was a basal layer of shredded newspaper and cardboard wastes to the thickness of 2 cm as a bulk material, water agent, and carbon-rich material to feed earthworms. This layer formed 10% of the total components. The second layer (formed 25% of the total components) was fresh grass clippings as nitrogen-rich material. The third one was 5 kg of rabbit manure (collected from the Agricultural Experiment Station, Faculty of Agriculture, Cairo University, Egypt) soaked in 10 L of tap water for one week and then added to the basin to feed worms (Munroe, 2007), to avoid the thermophilic stage during digestion. Some properties of the used rabbit manure are presented in Table 3. The soaked rabbit manure formed 40% of the total components. The fourth layer (formed 25% of the total components) was green fresh farm residues. Then, one kilogram (about 1000 worms) of Epigiec earthworms (*Eisenia foetida*, Red Wigglers), worm diameter 1–2 mm and worm length 120–150 mm was added to the basin. Every two days, beds were kept moist by water sprinkling and turned to maintain aeration. After 60 days from the beginning of the vermicomposting process, the raw materials became homogeneous, granular structures with a pleasant odor and dark brown color. Then, the manual selection was done to isolate earthworms from matured vermicompost. Some properties of the produced vermicompost are presented in Table 4.

The solid organic fertilizers were manually incorporated into the soil at the rate of 13.75 tons ha^{-1} vermicompost (1.43% N), 7.708 tons ha^{-1} pigeon manure (2.70% N), and for compost (0.90% N), 22.916 tons ha^{-1} were added. Pigeon manure was collected from the Agricultural Experiment Station, Faculty of Agriculture, Cairo University, Egypt (its properties are shown in Table 3). Commercial compost was purchased from Beni Suef Company for producing compost, in Egypt (its properties are shown in Table 3). Varying amounts of solid organic fertilizers were added to the soil (depending on their content of N) to eventually reach 60 units of N in the soil (as the Egyptian Ministry of Agriculture recommended for cucumber cultivation). Vermicompost tea was prepared by soaking 10 kg of the obtained matured vermicompost in 100 L of water (1:10 *w/v*) in a plastic drum with continuous agitation. After one-week, phosphoric acid (H_3PO_4, 85% conc.) was added slowly with agitation to adjust the solution's pH at 6.5. Furthermore, 5 L of sugarcane molasses as a source of glucose and 800 g of cake yeast were added directly to enrich the solution. The solution was left covered for 3 days under open field conditions. Pigeon manure tea was prepared as the vermicompost tea prepared. Both solutions were filtered using a nylon membrane. The vermicompost tea and pigeon manure tea were added through drip irrigation at the rate of 800 mL plant^{-1} 12 times^{-1} (equal to 16666 L ha^{-1}) for each. Some properties of the used teas are presented in Table 5. Regarding the mineral fertilizers (farmer practice) as a control treatment, the recommended N, P, and K fertilizers were applied. Here in this study, the triple superphosphate fertilizer (46% P_2O_5) was added during soil preparation at a rate of 27.78 tons ha^{-1}. Ammonium sulfate [$(NH_4)_2SO_4$, 20.5% N] and potassium sulfate (K_2SO_4, 50% K_2O) were added at the rate of 185.18 and 277.77 kg ha^{-1}, respectively, in two equal doses, 15 and 30 DAT. As well, magnesium sulfate ($MgSO_4$, MgO 16%) was added during soil preparation at a rate of 277.77 kg ha^{-1}, and calcium nitrate [$Ca(NO_3)_2$, 14% CaO and 15.5% N] was added at a rate of 2.31 tons ha^{-1} in two batches, during soil preparation and 45 DAT. In addition, chicken manure was added to the studied sandy loam soil during its preparation for cucumber cultivation at a rate of 19.44 tons ha^{-1} (its properties are shown in Table 3).

Assessments

Soil analysis

Soil samples were collected every 15 days after plant transplanting to detect the soil's chemically available concentration of nitrogen (N). In addition, soil samples were collected after plant harvest (120 DAT) at 0-30 cm depth. The collected samples were air dried, ground to pass through a 2 mm sieve, and prepared to determine pH, EC_e, concentration of available phosphorus (P) and available potassium (K), in addition to organic matter (OM) content in soil (Page et al. 1982).

Plant analysis

Samples of 3 plants of each treatment were taken 60 days from the cultivation date, to estimate plant height, no. of leaves plant^{-1}, total fresh and dry weights, as well as fruit length, fruit diameter, and no. of fruits plant^{-1}. After the plant harvest, cucumber yield was estimated. For detecting N concentration in the 5th leaf, three samples of each plot were collected every 15 days after plant transplanting till the end of the experiment and dried at 65°C in an air-forced oven for 48 h. Dried leaves were digested by H_2SO_4/H_2O_2 mixture and total N was determined using the Kjeldahl method according to the procedure outlined by Chapman and Pratt (1961).

Table-4. Some properties of the produced vermicompost.

Property	Unit	Value
Weight of 1 m^3	kg	720
Moisture content	%	48.0
pH (1:10 vermicompost: water suspension)	unitless	7.40
EC_e	dS m^{-1}	3.03
Total N	%	1.43
Organic matter	%	37.9
Organic carbon	%	22.0
Ash	%	62.1
C/N ratio		15.4
Total P as P_2O_5	%	0.86
Total K as K_2O	%	1.61
Humic acid	%	0.94
Fulvic acid	%	0.85
Weed seeds germination	%	nil
Pathogenic nematode	Larvae per 200 g soil	Not infected
Pathogenic fungi spp. *Fusarium, Rhizoctonia, Pythium, Phytophthora, Alternaria, and Verticillium*	Total count	Not infected
Biological N_2- fixers *Azospirillum spp.* *Azotobacter spp.*	CFU mL^{-1}	Not found
Plant growth regulators (PGRs)		
Gibberellic acid	µg g^{-1}	384
Cytokinin	µg g^{-1}	161
Total amino acids	µg g^{-1}	69.0

Profitability

The economic analysis was done by calculating the cultivation cost for different agro–inputs, i.e., greenhouse structure, hiring, electricity, irrigation, seedlings purchase, fertilizers, pesticides, labor, and other mandatory experimental requirements. The returns of applying both organic and mineral treatments were calculated ($ ha^{-1}) based on the local market price according to CIMMYT (1988) as follows:

Total income = Fruit yield x Price of cucumber yield ha^{-1} ($ ha^{-1}) ……. (1)
Net profit = Total cost – Total income ($ ha^{-1}) ……. (2)
Benefit/Cost (B/C) ratio = Net profit / Total cost ……. (3)

Statistical analysis

Data of each treatment were subjected to analysis of variance (ANOVA) according to Casella (2008) using the Costat software program. Duncan's multiple range test was used for distinguishing among the treatment means (at $p \leq 0.05$) ± standard errors.

Results

Soil

As shown in Table 6, the soil's chemical properties were significantly influenced by fertilization treatments. In this respect, the treatments of $PM_{50/50}$ as a ground application plus PMT through DI, $PM_{50/50}$ as a ground application plus VCT through DI, and $VC_{50/50}$ as a ground application plus PMT through DI significantly decreased soil pH. The treatments of $VC_{50/50}$, $PM_{50/50}$, and $COMP_{50/50}$ as ground applications decreased soil EC without any significant differences among them. The treatments of $COMP_{50/50}$ as a ground application plus PMT through DI, and $PM_{50/50}$ as a ground application plus PMT through DI (for the bioavailability of P and K), as well as all treatments, except the farmer practice as a control treatment (for the soil organic matter content), were the effective patterns, recording the greatest increases in the studied growing season.

Table-5. Some properties of the produced vermicompost tea and pigeon manure tea.

Property	Vermicompost tea	Pigeon manure tea
Color	Black	Black
pH (1:10 organic tea: water suspension)	6.77	7.29
EC (dS m^{-1})	25.3	21.6
Total N (%)	0.20	0.18
Organic matter (%)	22.1	23.4
Organic carbon (%)	12.8	13.6
C/N ratio	64.0	75.5
Available P (μg g^{-1})	3999	4405
Available K (μg g^{-1})	4910	6696
Humic acid (%)	1.50	0.61
Fulvic acid (%)	0.97	0.56
Weed seeds germination (%)	nil	nil
Pathogenic nematode (Larvae per 200 g soil)	Not infected	Not infected
Pathogenic fungi spp. *Fusarium, Rhizoctonia, Pythium, Phytophthora, Alternaria, and Verticillium*	Not infected	Not infected
Plant growth regulators (PGRs) Gibberellic acid (μg g^{-1}) Cytokinin (μg g^{-1})	500 231	581 306
Total amino acids (μg g^{-1})	0.15	0.18

Table-6. Effect of the studied treatments on pH, the electrical conductivity of salts, available phosphorus and potassium, and organic matter content in the investigated soil after plant harvest (120 DAT).

Treatment	pH (1:2.5 soil: water suspension)	EC_e (dS m^{-1})	Available P (μg g^{-1})	Available K (μg g^{-1})	OM (%)
$VC_{50/50}$ + VCT	7.28 ± 0.01cd	5.68 ± 0.05bc	51.87 ± 1.00c	215.0 ± 2.89d	1.36 ± 0.04a
$PM_{50/50}$ + VCT	7.10 ± 0.06de	5.81 ± 0.06ab	47.97 ± 0.35d	223.0 ± 1.73c	1.37 ± 0.04a
$COMP_{50/50}$ + VCT	7.75 ± 0.09a	5.88 ± 0.04a	51.03 ± 0.18c	212.0 ± 1.15de	1.38 ± 0.03a
$VC_{50/50}$ + PMT	7.10 ± 0.29de	5.54 ± 0.02c	57.55 ± 0.68b	222.5 ± 1.44c	1.39 ± 0.01a
$PM_{50/50}$ + PMT	6.80 ± 0.12e	5.63 ± 0.01c	58.32 ± 0.55ab	234.0 ± 0.58a	1.43 ± 0.00a
$COMP_{50/50}$ + PMT	7.65 ± 0.03ab	5.62 ± 0.01c	60.10 ± 0.26a	234.0 ± 1.15a	1.41 ± 0.02a
$VC_{50/50}$	7.25 ± 0.03cd	4.67 ± 0.05e	31.63 ± 0.55g	210.5 ± 0.29de	1.06 ± 0.01b
$PM_{50/50}$	7.50 ± 0.06abc	4.76 ± 0.03e	34.69 ± 0.74f	207.5 ± 0.29e	1.08 ± 0.01b
$COMP_{50/50}$	7.40 ± 0.06bcd	4.76 ± 0.01e	35.54 ± 0.67f	211.5 ± 0.87de	1.05 ± 0.02b
Farmer practice (Control)	7.20 ± 0.00cd	5.05 ± 0.09d	41.67 ± 0.59e	228.0 ± 1.15b	0.91 ± 0.00c

VC: Vermicompost, VCT: Vermicompost tea, PM: Pigeon manure, PMT: Pigeon manure tea, COMP: Compost. Values were the means of 3 replicates ± standard errors. Varied letters within columns indicate that there were significant differences at a 0.05 level of probability.

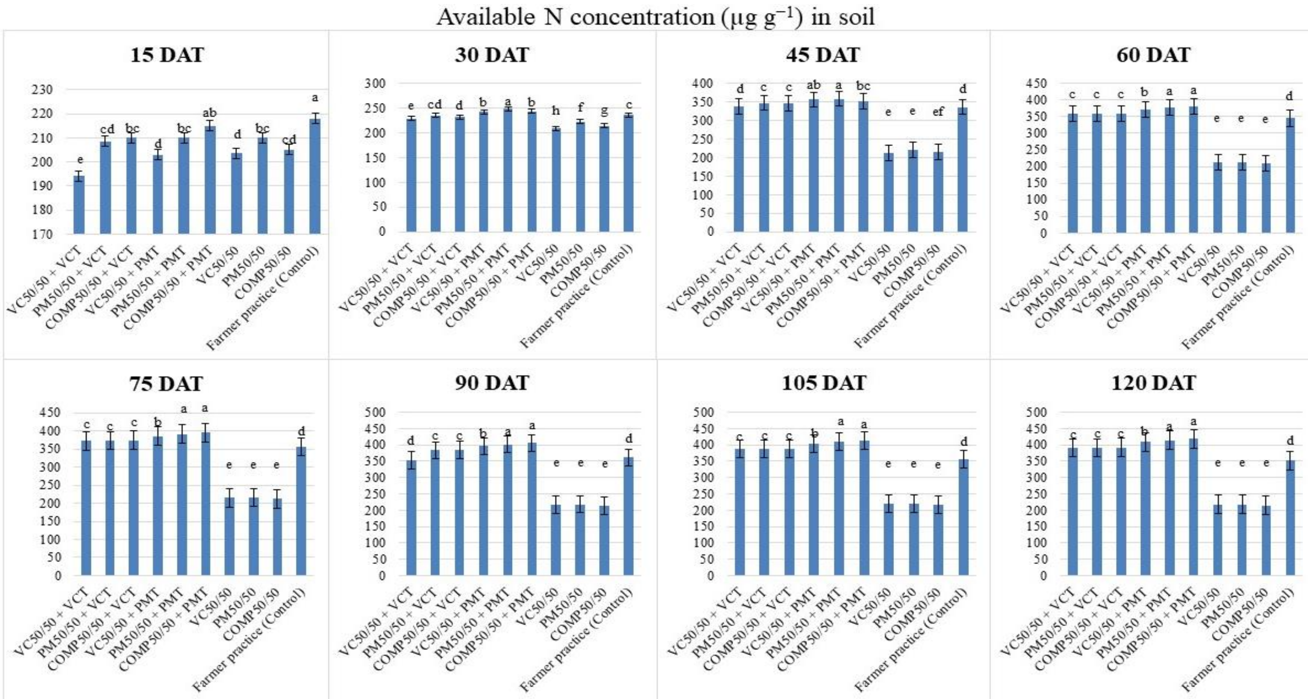

Figure-1. Available nitrogen concentration (μg g^{-1}) in the investigated soil every 15 days after cucumber plant transplanting (DAT) under the effect of the studied treatments. VC: Vermicompost, VCT: Vermicompost tea, PM: Pigeon manure, PMT: Pigeon manure tea, COMP: Compost. Values within columns were the means of 3 replicates ± standard errors. Varied letters outside columns indicate that there were significant differences at a 0.05 level of probability.

As illustrated in Fig. 1, the most distinctive increases in the available concentration of N in the studied soil during the investigated growing season were observed with the farmer practice (218 μg g^{-1}), and the treatment of $COMP_{50/50}$ as a ground application plus PMT through DI (215 μg g^{-1}) (for 15 DAT), the treatments of $PM_{50/50}$ as a ground application plus PMT through DI, $VC_{50/50}$ as a ground application plus PMT through DI, and $COMP_{50/50}$ as a ground application plus PMT through DI (for 30, 45, 60, 75, 90, 105, and 120 DAT). Unlike, the addition of $VC_{50/50}$, $PM_{50/50}$, and $COMP_{50/50}$ as ground applications caused decreases in the available N concentration in the studied soil starting from 45 DAT until the end of the experiment.

Plant

In the studied growing season, the farmer practice, $PM_{50/50}$ as a ground application plus VCT applied through DI, and $VC_{50/50}$ as a ground application plus PMT (for plant height); the farmer practice, $PM_{50/50}$ as a ground application plus PMT through DI, and $VC_{50/50}$ as a ground application plus PMT (for leaves number, plant fresh and dry weights) recorded the maximum values (Table 7). Accordingly, as a general observation, applying $PM_{50/50}$ as a ground application plus VCT through DI, $VC_{50/50}$ as a ground application plus PMT, and $PM_{50/50}$ as a ground application plus PMT applied through DI were the remarkable practices (equaling the traditional practice, the farmer practice) for enhancing almost cucumber growth and development. On the contrary, adding $VC_{50/50}$, $PM_{50/50}$, and $COMP_{50/50}$ as ground applications gave lower values of the studied vegetative growth parameters than adding combined applications between the studied treatments as a part added in solid form in soil and the other applied through DI as a nutrient solution.

Table-7. Effect of the studied treatments on the vegetative growth parameters of cucumber plants (at 60 DAT).

Treatment	Plant height (cm)	No. of leaves plant^{-1}	Total fresh weight (g plant^{-1})	Total dry weight (g plant^{-1})
$VC_{50/50}$ + VCT	152.0 ± 2.08d	22.00 ± 0.58bc	20.35 ± 0.56cd	6.19 ± 0.63ab
$PM_{50/50}$ + VCT	162.3 ± 1.20b	24.33 ± 0.67abc	19.68 ± 0.60de	6.59 ± 0.34a
$COMP_{50/50}$ + VCT	154.0 ± 1.15cd	21.67 ± 0.88c	17.83 ± 0.46f	5.00 ± 0.19c
$VC_{50/50}$ + PMT	162.0 ± 1.53b	25.00 ± 1.00ab	21.79 ± 0.29c	6.53 ± 0.35a
$PM_{50/50}$ + PMT	160.0 ± 1.15bc	25.67 ± 0.67a	24.01 ± 0.33b	6.36 ± 0.37a
$COMP_{50/50}$ + PMT	159.0 ± 1.53bc	24.00 ± 1.15abc	20.52 ± 0.33cd	5.27 ± 0.26bc
$VC_{50/50}$	148.7 ± 0.88d	17.00 ± 1.53d	18.49 ± 0.64ef	4.32 ± 0.27c
$PM_{50/50}$	142.0 ± 1.15e	16.67 ± 1.20d	21.57 ± 0.56c	4.84 ± 0.33c
$COMP_{50/50}$	117.0 ± 2.58f	15.33 ± 0.33d	19.09 ± 0.42def	4.63 ± 0.12c
Farmer practice (Control)	174.7 ± 3.78a	26.33 ± 0.88a	26.59 ± 1.03a	6.80 ± 0.19a

VC: Vermicompost, VCT: Vermicompost tea, PM: Pigeon manure, PMT: Pigeon manure tea, COMP: Compost. Values were the means of 3 replicates ± standard errors. Varied letters within columns indicate that there were significant differences at a 0.05 level of probability.

Table-8. Effect of the studied treatments on the yield traits of cucumber plants (at 60 DAT) and yield weight after plant harvest (120 DAT).

Treatment	Fruit length (cm)	Fruit diameter (cm)	No. of fruits plant^{-1}	Cucumber yield (kg plant^{-1})
$VC_{50/50}$ + VCT	16.50 ± 0.29abc	3.67 ± 0.17ab	8.33 ± 1.20abc	6.31 ± 0.12de
$PM_{50/50}$ + VCT	16.67 ± 0.33abc	3.67 ± 0.17ab	8.33 ± 0.33abc	6.58 ± 0.10cd
$COMP_{50/50}$ + VCT	16.33 ± 0.33bc	3.83 ± 0.19a	9.00 ± 0.58ab	5.87 ± 0.06f
$VC_{50/50}$ + PMT	17.00 ± 0.29ab	3.33 ± 0.16bc	9.33 ± 0.33a	6.85 ± 0.10c
$PM_{50/50}$ + PMT	16.83 ± 0.17abc	3.83 ± 0.17a	8.33 ± 1.25abc	7.82 ± 0.13b
$COMP_{50/50}$ + PMT	16.90 ± 0.10abc	4.00 ± 0.00a	7.67 ± 0.88abc	6.21 ± 0.13e
$VC_{50/50}$	16.13 ± 0.13c	3.17 ± 0.16c	6.00 ± 1.15c	3.88 ± 0.11g
$PM_{50/50}$	16.17 ± 0.17c	3.33 ± 0.16bc	6.33 ± 1.45bc	3.84 ± 0.05g
$COMP_{50/50}$	15.33 ± 0.17d	3.67 ± 0.17ab	6.00 ± 1.00c	3.40 ± 0.12h
Farmer practice (Control)	17.17 ± 0.18a	3.60 ± 0.06abc	10.00 ± 0.58a	8.30 ± 0.14a

VC: Vermicompost, VCT: Vermicompost tea, PM: Pigeon manure, PMT: Pigeon manure tea, COMP: Compost. Values were the means of 3 replicates ± standard errors. Varied letters within columns indicate that there were significant differences at a 0.05 level of probability.

As illustrated in Fig. 2, the most distinctive increases in N content in the 5th leaf of cucumber plants were observed with the treatments of $VC_{50/50}$ as a ground application plus VCT through DI (3.28%), $COMP_{50/50}$ as a ground application plus PMT through DI (2.89%), and $PM_{50/50}$ as a ground application plus PMT through DI (2.84%) which relatively near to that obtained by the control treatment (farmer practice, 2.95%), at 15 DAT. The treatment of $PM_{50/50}$ as a ground application plus PMT through DI achieved the highest remarkable values at 30, 90, and 105 DAT. While the treatment of control (farmer practice) gave higher values at 45, 60, 75, and 120 DAT. Unlike, the addition of $VC_{50/50}$, $PM_{50/50}$, and $COMP_{50/50}$ as ground applications, without applying VCT or PMT through DI, gave the lowest content of N in cucumber leaves during the studied growing season.

The beneficial impacts of $VC_{50/50}$ or $PM_{50/50}$ as ground applications plus PMT applied through DI extended also to the cucumber fruit quality (Table 8). In this context, $VC_{50/50}$ as a ground application plus PMT applied through DI (for fruit length); $COMP_{50/50}$ as a ground application plus PMT applied through DI, $PM_{50/50}$ as a ground application plus PMT applied through DI, and $COMP_{50/50}$ as a ground application plus VCT applied through DI (for fruit diameter); $VC_{50/50}$ as a ground application plus PMT applied through DI (for the number of fruits per plant); $PM_{50/50}$ as a ground application plus PMT applied through DI (for cucumber yield per plant) recorded high increases in the studied growing season, similar to that obtained by the farmer practice.

Profitability

The economic study showed that traditional treatment (control) was the most expensive practice (10668 \$ ha^{-1}), while organic treatments were the cheapest practice (7713 \$ ha^{-1}) (Table 9 and Fig. 3). Additionally, the highest gross and net returns (43812 \$ ha^{-1}), as well as benefit/cost ratio (5.68), were achieved with the application of the organic treatments.

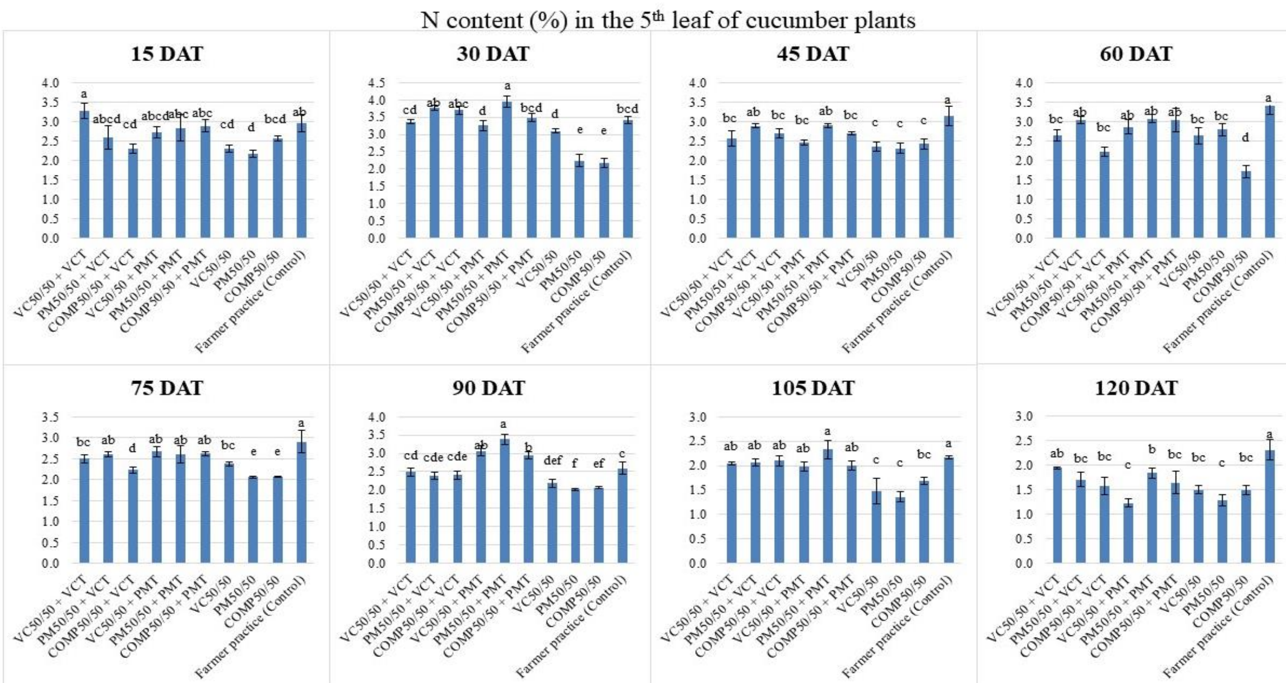

Figure- 2. Total nitrogen content (%) in the 5th leaf of cucumber plants every 15 days after transplanting (DAT) under the effect of the studied treatments. VC: Vermicompost, VCT: Vermicompost tea, PM: Pigeon manure, PMT: Pigeon manure tea, COMP: Compost. Values within columns were the means of 3 replicates ± standard errors. Varied letters outside columns indicate that there were significant differences at a 0.05 level of probability.

Table-9. Benefit-cost analysis for cucumber production under organic fertilization in comparison to traditional (mineral) ones.

Item	Conventional farming	Organic farming
Greenhouse structure (\$)	1067	1067
Hiring, electricity, and irrigation water (\$)	1067	1067
Seedlings (\$)	16875 plants × 0.10 \$ = 1687.5 \$	16875 plants × 0.10 \$ = 1687.5 \$
Fertilizers (\$)	4576.2	1830.5
Pesticides (\$)	915.2	605.08
Labors (\$)	1355.93	1355.93
Organic registration certificate (\$)	0.0	100
Total Cost (\$ ha^{-1})	10668.83	7713.43
Total yield (kg ha^{-1})	135000	101250
Total income (\$ ha^{-1})	135000 kg × 0.33 \$ = 45762.7 \$	101250 kg × 1.0 \$ = 101250 \$
Net profit (\$ ha^{-1})	10668.83 – 45762.7 = 35000	101250 – 7713.43 = 43812.5
Benefit-cost ratio	35000 ÷ 10668.83 = 3.281	43812.5 ÷ 7713.43 = 5.680
Prices were converted to \$ using an exchange rate in January 2023, 1\$ = 29.50 LE.		

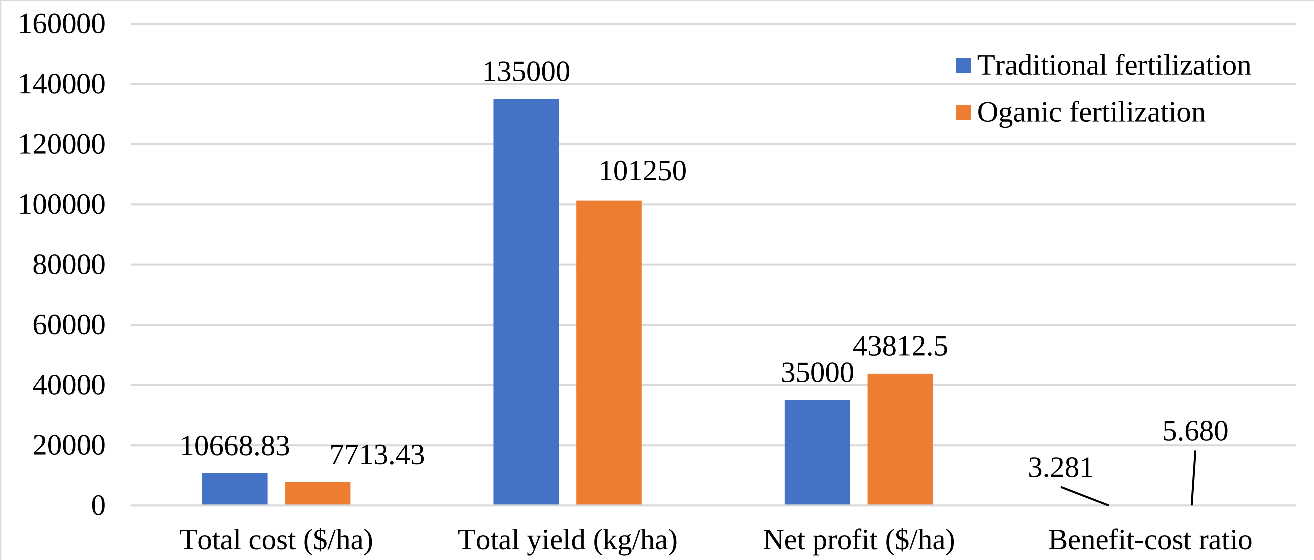

Figure-3. Benefit-cost ratio for cucumber production under organic fertilization in comparison to traditional ones.

Discussion

The soil used in the experiment (Table 1) was sandy loam in texture (USDA, 2010), and saline because of its EC_e value > 4 dS m^{-1} (LAS, 2014). Moreover, total N (0.05%) was deficient (McBride, 2015) and the soil had a low content of available P (6.22 µg g^{-1}) (Mallarino, 2000) which could slow down plant development. The OC and OM contents in the studied soil before cultivation (0.6 and 1.03%, respectively) were moderate (McBride, 2015), similar to available N and K (53 and 161 µg g^{-1}, respectively) (Pam and Brian, 2007). The $CaCO_3$ content (7.55%) was low, and the C/N ratio (12), according to Hill (2001), was considered normal and could result from low rainfall and high temperature during this period. It had a low content of available Fe, Mn, Zn, and Cu (0.78, 0.23, 0.14, and 0.04 µg g^{-1}, respectively) (Kabata-Pendias and Pendias, 2000). Soluble Na was dominant, and the co-ions were Cl^- followed by SO_4^{2-}. The soil was not infected with the eggs or larvae of pathogenic nematode. The classification of the water used for irrigation (Table 2) was low due to high EC, TSS, soluble ions, and pH (Ayers and Westcott, 1989).

The EC of the applied four organic materials (Table 3) was strongly saline as reported by LAS (2014). This could be because of the organic materials' high concentration of soluble salts. Moreover, the highest EC value of compost compared with pigeon manure supports the findings of Saka et al. (2017) and could be attributed to the high content of ash and nutrients. The pH of the chicken manure (8.52) was considered mild alkaline, whereas those of pigeon and rabbit manures (6.3 and 6.7, respectively) were mild acidic, while that of compost (7.2) was neutral (Pam and Brian, 2007). This could increase nutrient availability in the soil (Abd-Elrahman et al., 2012; Saka et al., 2017). Results clarified that chicken manure (for total N), rabbit manure (for total P_2O_5), and pigeon manure (for total K_2O) had the highest values. Rabbit manure gave the highest OC and OM contents (41.7 and 71.9%, respectively) as compared to the rest of other manures and compost, and this may be the reason for its high content of ions either cationic or anionic, especially phosphate ions. Chicken manure was rich in humic acid (0.98%), while pigeon manure was rich in fulvic acid (0.81%). The studied manures and compost were not infected with the pathogenic nematode or fungi. They were rich in N_2 fixers in the soil. Chicken and pigeon manures were rich in growth regulators and total amino acids. These findings agreed with those obtained by Ansari and Mahmood (2017); Awad and Ahmed (2019); Awad and Sweed (2020).

The produced vermicompost (Table 4) had considerable amounts of N, P_2O_5, K_2O, OC, OM, and ash (Saka et al., 2017; Abd El-Fattah et al., 2022; Abd-Elrahman et al., 2022b). In addition, vermicompost contained humic and fulvic acids with total concentrations of less than 1%, while had high amounts of gibberellic acid, cytokinin, and total amino acids (Esmaielpour et al., 2020; Olowoake et al., 2022). The pH (7.4) of the produced vermicompost was considered neutral and the EC (3.03 dS m^{-1}) was high (Wang et al., 2021). The produced vermicompost was not infected with the pathogenic nematode or fungi, and the biological N_2 fixers were not found (Hashem and Abd-Elrahman, 2016). The produced vermicompost tea and pigeon manure tea (Table 5) had high amounts of nutrients as a result that they produced from vermicompost and pigeon manure (Tables 3 and 4). The vermicompost tea had a pH value less than that of pigeon manure tea, on the contrary, the last one had an EC value less than the first one. The vermicompost tea had higher concentrations of total N (0.2%), and humic and fulvic acids (1.5 and 0.97%, respectively) than the produced pigeon manure tea, while pigeon manure tea had higher concentrations of available P and K (4405 and 6696 µg g^{-1}, respectively), and OC and OM (13.6 and 23.4%, respectively) than the produced vermicompost tea. Pigeon manure tea also had higher concentrations of plant growth regulators and total amino acids. Both teas were not infected with the pathogenic nematode or fungi (Haggag et al., 2015; Arosha and Sarvananda, 2022; Mihoub et al., 2022). Arosha and Sarvananda (2022) found that vermicompost tea had more viable microorganisms (107-109 CFU mL^{-1}). It is a liquid biofertilizer that contains beneficial bacteria and fungi that enrich the soil and aerobic microorganisms and suppress soil-borne diseases (Hashem and Abd-Elrahman, 2016; Arosha and Sarvananda, 2022).

Soil physio-biochemical properties are influential indicators of soil health and fertility and can also be used to assess the plants' growth. The treatments of $PM_{50/50}$ or $COMP_{50/50}$ as ground applications plus PMT applied through DI influenced soil physio-biochemical properties, including the soil pH, OM, and available nutrients which contributed to the quality and yield development of grown cucumber plants. These treatments significantly decreased soil pH and increased OM and available amounts of P and K (Table 6). The EC values in soil (Table 6) decreased due to applying the treatments of $VC_{50/50}$, $PM_{50/50}$, and $COMP_{50/50}$ as ground applications, without any significant differences among them. Vermicompost has a high sorption ability (Wang et al., 2021) that makes it adsorbs salts and organic acids produced during the OM decomposition process, resulting in lower soil EC values. The favorable effect of the organic solid fertilizers in decreasing EC may be attributed to the enhancement in porosity and infiltration, which is reflected in increasing salt leaching (Awad and Ahmed, 2019; Awad and Sweed, 2020). The increment of salts in soil caused due to the co-application of organic aqueous extracts with organic solid ones (Hashem and Abd-Elrahman, 2016). The soil OM content was significantly increased by all the organic treatments because of the large amount of carbon in the PM and VC and their teas (Wang et al., 2021). During the OM decomposition, the organic acids were released resulting in decreasing soil pH and the nutrients will be readily available for uptake by plants (Ansari and Mahmood, 2017; Thongney et al., 2018). Mihoub et al. (2022) found that organic supplements such as PMT have been reported to increase available P concentration in calcareous soils, by promoting microbial activity and improving P mobilization. So, we can conclude that the co-application of organic aqueous extracts with organic solid ones enhanced the soil's physicochemical and biological properties.

Furthermore, the increase in available N with time (Fig. 1) due to the application of organic treatments might also be attributed to the greater multiplication of microbes caused by adding organic fertilizers to mineralize organic N into inorganic forms (Awad and Sweed, 2020). Nitrogen release after the application of $VC_{50/50}$, $PM_{50/50}$, or $COMP_{50/50}$ as ground applications plus PMT applied through DI with low initial N content is favored in sandy soils where the grazing capacity of microbes is better (Saka et al., 2017). Depending on biotic and abiotic factors, the treatments differ in capacity to release mineral N. In our study, the superiority of $VC_{50/50}$, $PM_{50/50}$, or $COMP_{50/50}$ as ground applications plus adding PMT through DI over their additions alone or even by the farmer practice is probably due to their initial high total N and low C/N ratios (Mubarak et al., 2010). The addition of organic fertilizers ensures the continued availability of N in the soil and supply plants with its requirements throughout the growth period as compared to the mineral applications of N and how mineral N faces some processes that decrease its availability and increase its losses in the soil such as leaching, and volatilization (Saka et al., 2017; Wang et al., 2021).

The treatments of $VC_{50/50}$, and $PM_{50/50}$ as ground applications plus PMT applied through DI gave high values of vegetative growth parameters of cucumber plants, i.e., plant height, number of leaves per plant, and total fresh and dry weights (Table 7). Adding vermicompost improves soil structure, benefiting microbial activity when it decomposes, which promotes plant growth and productivity (Wang et al., 2021). The enhancement in cucumber plant growth due to the application of PM and VC was related to improving soil physio-biochemical properties that benefit plant growth and productivity (Esmaielpour et al., 2020; Olowoake et al., 2022). The application of PM and VC and their teas contain different crop growth hormones, significantly improving cucumber growth and yield quality (Haggag et al., 2015; Salem et al., 2018; Arosha and Sarvananda, 2022; Mihoub et al., 2022). The positive effect of the control treatment (farmer practice) on cucumber vegetative growth parameters was due to the increased solubility of added nutrients and they were readily available in the soil (Steiner et al., 2012; Abd-Elrahman and Taha, 2018; Younis et al., 2021).

Concerning the N content in the fifth leaf of cucumber plants with time (Fig. 2), results showed that overall, at the beginning time of the growing season, the control treatment (farmer practice) gave the highest content compared to the effect of the organic treatments. It may be due to the addition of mineral N fertilizers increasing the solubility of N which is easily taken up by cucumber plants. On the other hand, the decomposition of OM and mineralization of organic N in the organic treatments needed time depending on their initial total N and C/N ratio (Abd-Elrahman et al., 2022a). After that, the effect of organic treatments appeared, the treatments of $VC_{50/50}$, $PM_{50/50}$, or $COMP_{50/50}$ as ground applications plus adding PMT through DI gave high content of N in the fifth leaf of cucumber plants and the effect was continued till the end of the experiment, parallel with that observed in the available concentration of N in soil with time (Fig. 1). Vermicompost includes essential macro- and micronutrients, which are easily up taken by crops (Wang et al., 2021; Olowoake et al., 2022). Steiner et al. (2012) reported that the application of organic fertilizers can provide a sustainable agricultural system by increasing nutrient use efficiency and enhancing soil quality. Arosha and Sarvananda (2022) reported that VCT is rich in essential nutrients and growth regulators, e.g., indole acetic acid, cytokinins, and gibberellins. Also, Mihoub et al. (2022) found similar findings about PMT. On the other hand, the treatments of $VC_{50/50}$, $PM_{50/50}$, or $COMP_{50/50}$ as ground applications without injecting liquid fertilizers through DI gave the lowest contents of N in the leaves of cucumber plants, which may be due to their lowering content of N if they were added alone.

The encouraging effect of the treatments of $VC_{50/50}$, and $PM_{50/50}$ as ground applications plus adding PMT through DI were expanded from giving vigor plant growth to giving high quality and yield of cucumber, i.e., fruit length, fruit diameter, number of fruits per plant, and total fruit yield per plant (Table 8). Vermicompost includes essential nutrients, which are easily absorbed by cucumber (Wang et al., 2021), that enhance the photosynthesis process, cell enlargement, and cell division, eventually enhancing the cucumber's growth and yield-contributing properties (Olowoake et al., 2022). Moreover, VC and its extracted tea contain different growth hormones that significantly improve fruit quality and yield (Hashem and Abd-Elrahman, 2016). Ansari and Mahmood (2017) reported that PM and PMT were considered to produce bioactive compounds such as many vitamins and phytohormones which accelerated plant growth and yield. The increase in the total yield may be due to the positive effect of organic materials such as VC, PM, and COMP on soil aggregation, the balance between soil aeration and soil-water content and eventually making good environmental conditions for the roots to absorb more nutrients which reflect on giving vigor plant growth and yield. Furthermore, adding VCT or PMT through DI that are rich in growth hormones and vitamins activates plant growth and gives high quality and yield (Haggag et al., 2015; Thongney et al., 2018; Esmaielpour et al., 2020).

The economic benefits (Table 9 and Fig. 3) of conventional and non-conventional fertilizer usage were determined by seed prices, fertilizer rates, and how the plant responded to the application of fertilizers. The economic study showed higher net revenues for organic (non-conventional) treatments as compared to conventional treatments on cucumber plants. The organic treatments supply a more secure proportion of necessary nutrients that could justify their highest return (Abd El-Fattah et al., 2022; Olowoake et al., 2022).

Conclusion

It could be concluded that the treatments of $VC_{50/50}$ or $PM_{50/50}$ as ground applications plus adding VCT or PMT through DI gave the most distinctive increases in the available concentration of N in the studied soil during the investigated growing season. The same treatments enhanced the cucumber plant growth parameters, yield traits, and the total concentration of N in the fifth leaf of cucumber plants throughout the experimental period. Additionally, the highest benefit/cost ratio was achieved with the application of organic treatments as compared to the farmer's practice (using mineral fertilizers). So, the study recommends applying these organic treatments to enrich the soil with N and enhance the quality and yield traits of cucumbers.

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Contribution of Authors

Lela KM: Designed research methodology, collected and analyzed data, read and approved the manuscript.
El-Sebaay AS: Designed research methodology, analysed and interpreted data, read and approved the manuscript.
Abd-Elrahman SH: Designed research methodology, analysed and interpreted data and wrote and edited the manuscript.
Elbordiny MM: Designed research methodology, analysed and interpreted data, read and approved the manuscript.

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