Egyptian Journal of Soil Science

http://ejss.journals.ekb.eg/

Impact of Different Fertilizers on Black Cumin (*Nigella Sativa* L) Plants and Their Relation to Release Kinetics of Nitrogen and Phosphorus

Mostafa Y. Khalafalla, Yasser A. Sayed, Hassan M. Al-Sayed and **Ahmed M. Ali**

Department of Soils and Water, Faculty of Agriculture, Al-Azhar University, Assiut 71524, Egypt

NITROGEN (N) and phosphorus (P) released from different fertilizers to soil solution is a factor that affects soil fertility and plant growth. To evaluate the impacts of amending soil with organic, chemical and bio-fertilizers solely or in combinations for uprising N, P available contents in soil and increasing the growth of black cumin (*Nigella sativa* L) plants. The consequences of these additives on soil chemical properties were a matter of concern herein. To attain this aim, incubation and a pot experiment was conducting at 100% urea formaldehyde, 50% level of adding rabbit manure + 50% urea formaldehyde with or without bio-fertilizer, control without fertilization and bio-fertilizer single in a randomized block design which considering six equations (Zero-order, first-order equation, second-order equation, Pseudo-second-order, power function, and parabolic diffusion model) were used to describe variations among released N and P with incubation time. The results demonstrated that using chemical, organic, and bio-fertilizer resulted in considerable decrease in soil pH and increases in organic matter (SOM) and nutrients availability (N and P) by time progress for all treatments. Compared to other equations, the pseudo-second models provided a better description of the kinetics of changes in released N and P contents with time, with R^2 ranging from 0.99 to 1.00. The results show that the application of 50% Rabbit manure + 50% Urea formaldehyde + Bio-fertilizer (RUBF) significantly enhanced parameters of black cumin plants such as shoot dry weight, plant height, and stem diameter, chlorophyll a, b, and carotenoids ratio, dry weight capsules, number of capsules, and seed weight/plant. Our study is useful when using rabbit manure, ureaform and bio-fertilizers. That can be improving soil chemical properties, supplying available nutrients, the release kinetics and the factors related to the release of nutrients from these fertilizers are essential in planning strategies of nutrient management, additionally, boosted the growth, plants quality, yield and photosynthetic pigments.

Keywords: Nitrogen fertilizer, Phosphorus fractions, P release, Release kinetics.

1. Introduction

Nigella sativa L., known as black cumin, is an annual plant in the Ranunculaceae family. As medicinal plant, the seeds can be used as food and herb (Ahmad et al., 2013), they have a high antioxidant capacity and therefore are believed to have benefits for improving human health i.e., the immune digestive and cardiovascular systems (Tembhurne et al., 2014). It may also help in treatment of certain skin conditions, migraines, and diabetes (Yimer et al., 2019). Even though organic fertilization doesn't include much in the way of nutrients, it increases soil fertility and is essential to plant life, either directly by providing nutrients or indirectly by changing the physiological and biochemical pathways of the plant (Khosropour et al., 2021; Nasiroleslami et al., 2021). Rabbit manure is a good source as organic fertilizers with a high organic matter content and macro- and micronutrients that affect plant growth growth is rabbit manure (Al-Sayed et al., 2024).

There is proof that using organic fertilizers enhances the physical, chemical, and biological characteristics of soils. Rabbit dung is one of these fertilizers that decrease the pH and increase cation exchange capacity, organic carbon content, total fungus and bacteria, and organic matter content in soil ((El-Mogy et. al., 2020; Ikrarwati et al., 2021; Li et al., 2022). Also, bio-fertilizer such as *Azotobacter chroococcum* and *Azospirillum brasilense* play a prominent role in plant growth because they contain growth-promoting factors such as enzymes and hormones besides being nitrogen fixers and have the capability to increase mineral solubilization (Al-Sayed et al., 2022; Darakeh et al., 2022).

Generally, bio-fertilizers and rabbit manure are considered environmentally friendly fertilizers (Al-Sayed et al., 2024). Because slow-release fertilizers can release nitrogen (N) on a schedule that aims to

*Corresponding author e-mail: HassanMohamed.4419@azhar.edu.eg
Received: 21/03/2024; Accepted: 27/04/2024
DOI: 10.21608/EJSS.2024.278452.1740

better coordinate with crop needs, hence reducing nitrogen losses to the environment, applying such fertilizers is a good strategy to increase nitrogen use efficiency (Chalk et al., 2015). The application of rabbit manure (RM) in conjunction with chemical fertilizers has been shown to have a particularly positive impact on crop yield, quality and increased the soil organic matter (OM), N, P, K, Ca and Mg (Adekiya et al., 2020; El-Beltagi et. al., 2023). Additionally, incorporating organic amendments shows significant improvements in soil physical structure, increased nutrient content, and microbial variety than chemical fertilizers alone (He et al., 2024).

The kinetics and rate of mineralization determine whether organic feed stocks are a good source of nutrients (Murugan and Swarnam, 2013). The kinetics examines how quickly chemical reactions occur and its rate on through the change in chemical concentration over time. Kinetics enables farmers to improve agricultural productivity via determining the kinetics and rate of mineralization of several available organic sources. Both factors (Chemical reaction and its rate) are dependent on soil temperature, moisture content, soil type and characteristics of the used organic matter, microbial activity and management techniques (Grzyb et al., 2020; Uddin et al., 2021). Although both inorganic and organic phosphorus (P) are widely distributed in most croplands, their strong reactivity with particular metals prevents them from being directly absorbed by living things (He et al., 2023). This is because, phosphorus is adsorbed to mineral surfaces, locked inside primary or secondary mineral particles, or immobilized inside organic material (Helfenstein *et al*., 2020). In order to reduce the negative environmental effects of farming, rationalizing the use of chemical fertilizers is thought to be one of the most important concerns for sustainable agriculture (Wu et al., 2021). In addition to giving plants nutrients, organic or bio-fertilizers can improve the agricultural ecosystems' long-term sustainability (Shaji et al., 2021). These also include reducing the dangers of over fertilization and groundwater pollution (Moghaddam et al., 2021), enhancing the qualities and attributes of the soil, and preserving soil fertility (Shaji et al., 2021). The behavior of the continuous interactions between various ions in the soil solution and the solid phase over time must be defined using the kinetics concept, and the release of P and N from the soil can be better visualized using the thermodynamic and dynamics concepts. One of the most significant and practical ways of evaluating and foreseeing the chemistry and condition of numerous nutrients is the kinetic concept (Toor and Bahl 199). Generally, some kinetic models such as the pseudo-second order, first, second-order, energy function, equivalent diffusion and Elovitch equations to measure release of nutrients in soil, (Abdu 2013; Ranjbar and Jalali, 2014). There are few references about the effects of different types of fertilizers on the kinetics of some macronutrients under black cumin plants. Additionally, few studies compare the effects of applied organic and slow chemical amendments on the release of nitrogen and phosphorous.

The objective of this work was to examine the effects of rabbit manure, ureaform and bio-fertilizer on the chemical characteristics of soil as well as the kinetics of N and P release and compare the response of black cumin plants to application dose from these fertilizers. The hypothesis proposed in this study is that combination of manure rabbit manure, ureaform and bio-fertilizer, can increase N, P release, growth and yield of black cumin plants.

2. Materials and Methods

2.1 Soil materials

A soil surface sample was collected from the topsoil (0-30 cm) of the experimental farm within the research area of the Department of Soil Science, Al-Al-Azhar University, Assiut Egypt, Faculty of Agriculture. This sample was air-dried, crushed, and passed through a 2 mm sieve. Physical and chemical characteristics were examined according to Sparks et al. (2020) and Klute (1986) are shown in Table (1).

Table 1. Physico-chemical properties of the tested soil.

Property	Unit	Value
Sand	(g kg^{-1})	405
Silt	(g kg^{-1})	310
Clay	(g kg^{-1})	285
Texture	-	clay loam
Bulk density	(Mg/m^3)	1.57
Soil pH (1: 2.5)	-	8.1
Soil EC (1: 2.5)	(dS m^{-1})	0.93
Organic matter	(g kg^{-1})	13.5
Available-N	(mg kg^{-1})	56.5
Available-P	(mg kg^{-1})	5.28
Available-K	(mg kg^{-1})	352
$CaCO_3$	(g kg^{-1})	21

2.2 Incubation experiment

An experiment for incubation was set up in the Department of Soils and Water Laboratory, Faculty of Agriculture, Al-Azhar University, Assiut, Egypt. For this study, the addition of 60 N units from several types of fertilizers were chosen, including rabbit manure (1.54% N) and urea formaldehyde (40% N). The soil was then thoroughly wet, and 10 ml of liquid bio-fertilizer containing 1:1 ratio of *Azotobacter chroococcum and Azospirillum brasiliense* were sprayed onto the top layer of soil containing 1×10^6 colony mL^{-1}. The tested bio-fertilizers were brought from the National Research Center (NRC), Giza, Egypt. Whereas rabbit manure was obtained from the Animal Production Farm, Faculty of Agriculture Assiut University Assiut, Egypt. The rabbit manure was crushed using a stainless-steel mill and sieved with a 2 mm sieve it was applied at a rate of 9.27 t ha^{-1} and the slowacting mineral nitrogen fertilizer urea formaldehyde was applied at a rate of 375 kg ha^{-1}. Chemical properties of rabbit manure were measured which are shown in Table (2). Therefore, five treatments: Control without fertilization as (CK), 100% Urea formaldehyde fertilizer (at a rate of 0.038 g urea formaldehyde/250 g soil sample) as (UF), Bio-fertilizer as (BF), 50% Rabbit manure + 50% Urea formaldehyde (at a rate of 0.49 g rabbit manure + 0.019 g urea formaldehyde/250 g soil sample) as (RUF) and 50% Rabbit manure + 50% Urea formaldehyde + Bio-fertilizer as (RUBF) were used. In a laboratory setting at 25-30 ^{o}C, five incubation durations of 60, 45, 30, 14 and 7 days were carried out to each treatment. A total of 75 experimental units were formed by grouping the treatments into randomized block designs with three replications. Every week, the treatments' moisture content was checked and adjusted, which had been wetted to 70 % from field capacity. By the end each incubation period, soil samples were collected and tested for electrical conductivity (EC) using a conductivity meter and soil pH using a digital pH meter in 1:2.5 (soil/water) suspensions (Jackson, 1973). The Walkly-Black method was utilized to determine the amount of organic matter, available N and P were determined according to Jackson (1973).

Table 2. Chemical properties of the rabbit manure.

pH (1: 2.5)	EC (dS/m) (1:2.5)	N %	Organic carbon %	K_2O %	P_2O_5 %
7.10	**8.40**	**1.54**	**10.60**	**1.00**	**1.38**

2.3 Kinetics of nitrogen and phosphorus in soil

The rate of nutrition transformation and related chemical reactions can be ascertained with the use of kinetics. It also helps to define the characteristics of a chemical reaction and gather and analyze data about the process of the reaction. Table (3) provided the equations used to fit the kinetics data of nitrogen and phosphorus in the investigated soil. By using the coefficient of determination (R^2), each kinetic model was examined.

Table 3. Kinetics models fitted to P forms versus time data.

Model	Equation	Parameter
Zero order	$C_A = C_{A0} + k_A t$	k_A is rate coefficient
First order	$\ln C_A = \ln C_{A0} + k_A t$	k_A is first-order rate coefficient
Second order	$1/C_A = 1/C_{A0} + k_A t$	k_A is second-order rate coefficient
Pseudo-second-order	$t/Q_{t-2} = 1/k_2 Q^2_{e-2} + t/ Q_{t-2}$	k'_2 is pseudo-second-order rate coefficient
Power function	$\text{In } C_A = \ln k_A + b \ln t$	k_A is rate coefficient and b is empirical constant
Parabolic diffusion	$CA = Rt^{1/2} + C$	R is diffusion rate constant

2.4 Pot experiment

Air-dried soil was packed in plastic pots according to Air-dried soil was packed in plastic pots according to the concentrations and mixing ratios of fertilizer types mentioned previously which were used in the incubation experiment. The recommended N dose of Black cumin was 375 kg N ha^{-1} according to the Egyptian fertilization recommendations. All the organic and inorganic fertilizers were mixed with the soil before cultivation. The plastic pots were of dimensions (30 cm in diameter, 35 cm in height) which was filled with sixteen kg of soil and mixed well with the tested material and the pots were then distributed randomly. Each treatment had five replicates, resulting in a total of 25 pots. Black cumin, selected as a local variety and a winter crop, was obtained from Al-Awamer Research Station, Agriculture Research Center, Assiut, Egypt, which was planted on the 8th November 2022 with a rate of 5 seeds per pot then thinned to two plants per pot two weeks after planting. The plants were irrigated every 5 days to keep soil moisture content at 70% of field capacity. The experiment lasted within the greenhouse conditions, the mean long-term temperatures and relative humidity are 24.9 °C and 38.04%, respectively from November to May month (Fig. 2) until the maturity stage. Plant samples were taken at harvest (1st May 2023). Fresh samples of plants were collected after 100 days to measure Chlorophyll-A, Chlorophyll-B and carotenoid contents according to a protocol approved by Lichtenthaler (1987).

The growth parameters such as plant height, shoot dry weight, stem diameter, dry weight capsule, and number of capsules were also recorded. Plant samples were taken at the experiment end; the plant sample was ground kept for chemical analysis. Using H_2SO_4-$HClO_4$ acid mixture, the total content of the nitrogen, phosphorus and potassium nutrients in the plant material was estimated according to Zarcinas et al., (1987). The meteorological data of the experimental site during the period of the study (Fig. 1) and the complete methodology of this study is depicted in (Fig. 2).

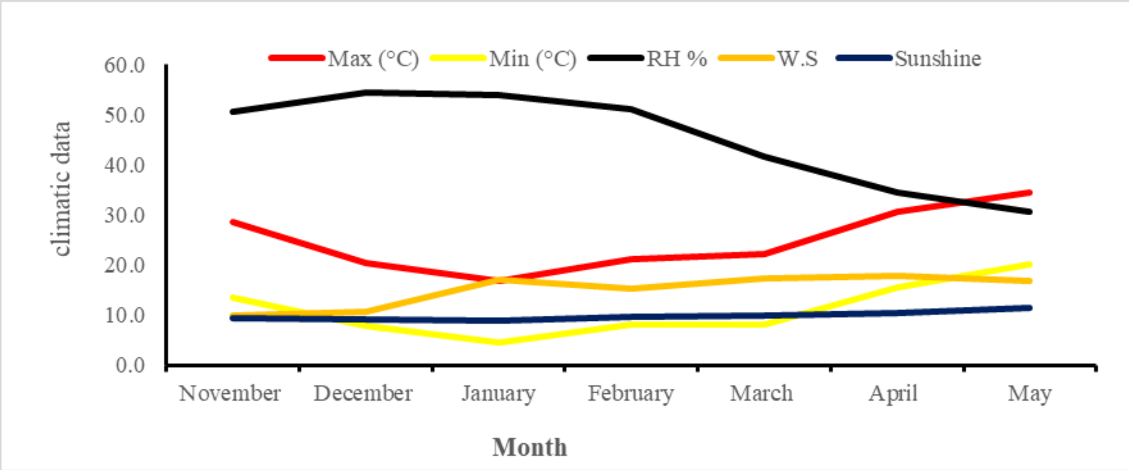

Fig. 1. Basic climatic data of the experimental site during the period of the study. Max, maximum temperature (°C); Min, minimum temperature (°C); *RH*, relative humidity (%); *W.S*, wind speed (km/h).

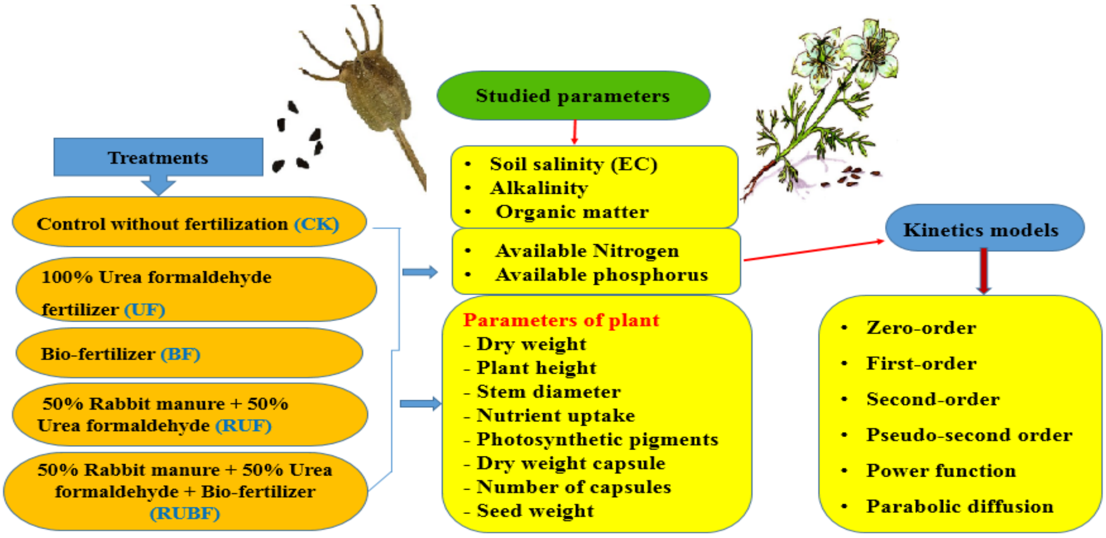

Fig. 2. General description of the research paper.

2.5. Statistical analyses

The analysis of variance (ANOVA) at a 5% level of probability was used to test the significance of differences between the treatments. Data analysis was conducted using a one-way analysis of variance via Costat software (Steel and Torrie, 1986).

3. Results

3.1 Soil chemical characteristics

Application of all types of fertilizers to soil caused a decrease in soil acidity compared to the unamended control (Fig. 3). The soil pH declined as the time proceeded for all treatments. After 14-days of incubation, exhibited a rapid decrease of soil pH with all treatments was observed. The lowest value (7.96) of soil acidity was observed by applying 50% rabbit manure + 50% urea formaldehydes + bio-fertilizer (RUBF) treatment after 60 days. The soil pH ranged between 8.11-8.13, 8.01-8.12, 7.98-8.09 and 7.96-8.08 for BF, UF, RUF and RUBF treatments, respectively under incubation period. The evolution of salinity in the soil over time is depicted in Fig. (4). Soil salinity (EC) increased as a result of the application of 50% rabbit manure + 50% urea formaldehydes (RUF) and RUBF treatments in comparison with control CK treatment. While soil EC declined with BF and UF treatments compared with the CK treatment. In general, data indicated that the soil EC from BF and UF treatments is less than that resulted from CK treatment after incubation periods, while soil EC from RUBF treatment is high than that resulted from CK treatment after incubation periods. The highest value of soil EC (1.07 dS m^{-1}) was recorded after 14 days of RUBF treatment. The lowest one (0.68 dS m^{-1}) was recorded after 60 days of BF treatment.

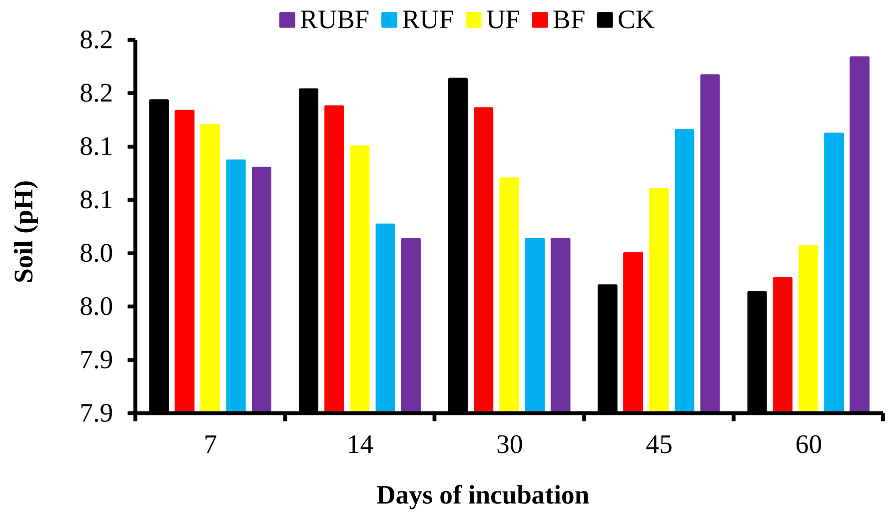

Fig. 3. Effect of fertilizer types on soil pH under incubation periods.

Control without fertilization= (CK), 50% Urea formaldehyde fertilizer= (UF), Bio-fertilizer= (BF), 50% Rabbit manure + 50% Urea formaldehyde = (RUF) and 50% Rabbit manure + 50% Urea formaldehyde + Bio-fertilizer= (RUBF).

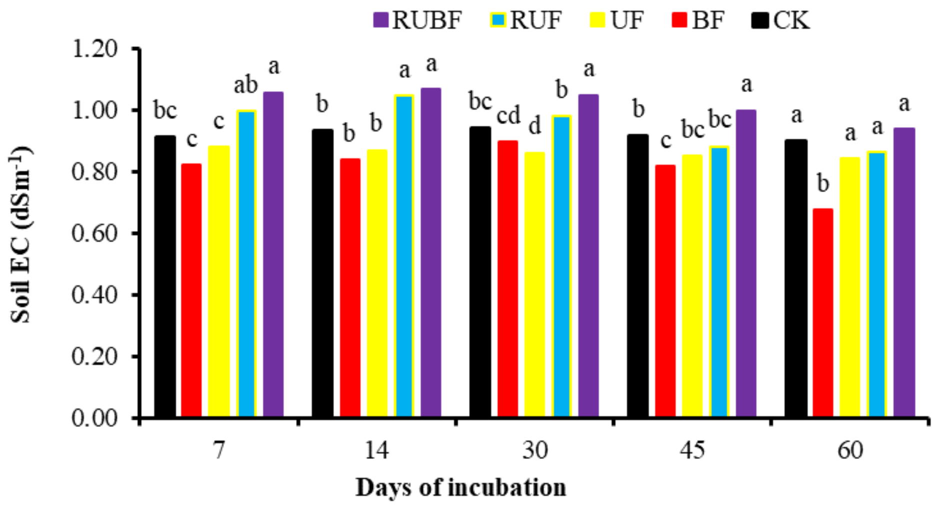

Fig. 4. Effect of fertilizer types on soil EC under incubation periods.

Control without fertilization= (CK), 50% Urea formaldehyde fertilizer= (UF), Bio-fertilizer= (BF), 50% Rabbit manure + 50% Urea formaldehyde = (RUF) and 50% Rabbit manure + 50% Urea formaldehyde + Bio-fertilizer= (RUBF). The same letter indicates insignificant difference according to Duncan's test at $p < 0.05$.

Soil organic matter (SOM) of soil increased with addition of all fertilizer types (Fig. 5). The highest values of soil organic matter were observed due to the application of RU treatment under incubation periods in comparison with other treatments. In general, the soil organic matter declined as time proceeded for all treatments. The soil organic matter ranged between 1.12-1.03, 1.01-1.12, 1.05-1.17 and 1.00-1.13 g kg^{-1} for BF, UF, RUF and RUBF treatments, respectively under incubation periods.

3.2 Nitrogen Kinetics and its release

Fig. (6) illustrates the influence of various fertilizer types on nitrogen release through different incubation periods. The available nitrogen content gradually increased with various fertilizer types application over control (CK). The highest available nitrogen was recorded with RUBF (80.78 mg kg^{-1}) followed by RUF (78.76 mg kg^{-1}) which increased by about 19.68% and 16.67%, respectively, over the control (CK). While the lowest available nitrogen (70.09 mg kg^{-1}) was recorded for BF treatment with 3.84% more than the control under 60 days. It is observed that the available nitrogen content from BF treatment is less than that from either RUF or RUBF treatment. However, among fertilizer types the available nitrogen content was numerically in the order: BF< UF< RUF< RUBF.

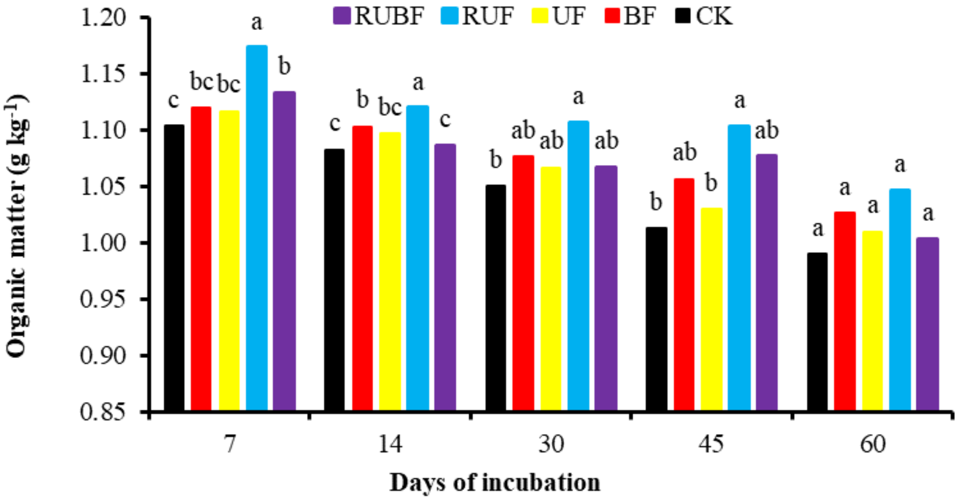

Fig. 5. Effect of fertilizer types on organic matter under incubation periods.

Control without fertilization= (CK), 50% Urea formaldehyde fertilizer= (UF), Bio-fertilizer= (BF), 50% Rabbit manure + 50% Urea formaldehyde = (RUF) and 50% Rabbit manure + 50% Urea formaldehyde + Bio-fertilizer= (RUBF). The same letter indicates insignificant difference according to Duncan's test at $p < 0.05$.

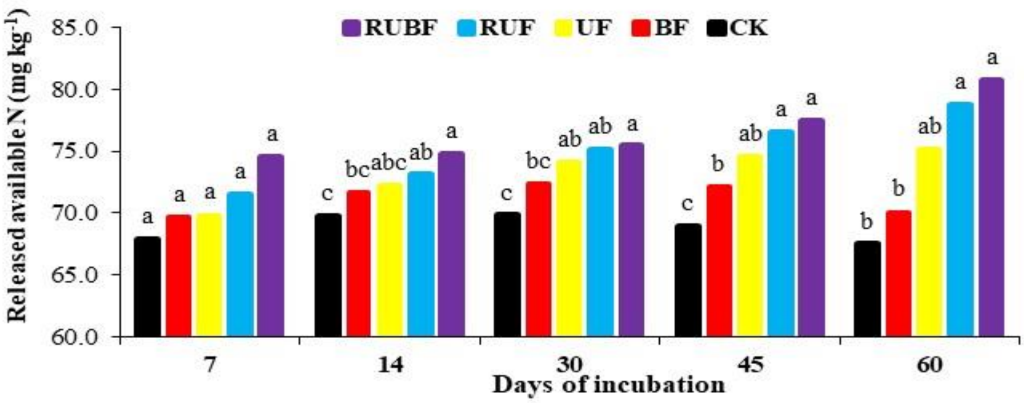

Fig. 6. Effect of fertilizer types on available nitrogen release during the incubation periods.

Control without fertilization= (CK), 50% Urea formaldehyde fertilizer= (UF), Bio-fertilizer= (BF), 50% Rabbit manure + 50% Urea formaldehyde = (RUF) and 50% Rabbit manure + 50% Urea formaldehyde + Bio-fertilizer= (RUBF). The same letter indicates insignificant difference according to Duncan's test at $p < 0.05$.

Six equations (Zero, First, Second-order, Pseudo-second order, Power function and Parabolic diffusion) were tested to study the kinetics of nitrogen release from different fertilizers in soil clay loam (Tables 4 and 5). In general, the correlation coefficient (R^2) was used to compare the equations. It indicates how well the experiment results match the theoretical results of these kinetic equations. The Pseudo-second order equation (R^2= 0.99–1.00) is the best kinetic equation for explaining the release of nitrogen in the soil compared to other equations. The Pseudo-second order kinetic constants of nitrogen resulted from different treatments were CK (-0.0336), BF (-0.0469), UF (0.0196) RUF (0.0101) and RUBF (0.0094). Negative constant values indicate that there is not much nitrogen being released, but increasing values of constant suggest that there is more nitrogen being released. The coefficient of determination (R^2) using the Pseudo-second order kinetic equation varies between 0.99 (CK, BF, RUF and RUBF) and 1.00 (UF). When UF, RUF, and RUBF are applied, both k_2 and Qe_{-2} increases, suggesting that fertilizer types can enhance both the release rate and released compared to the unamended control, Q_{e-2} of treatment (RUBF) is most, Q_{e-2} of treatment (RUF) is next while Q_{e-2} of Ureaform fertilizer (UF) is smallest.

Table 4. Kinetic parameters and R^2 of the Zero, First and Second-order describing the kinetic of nitrogen release.

Treatments	Zero-order			First-order			Second-order		
	Q_e	K_0	R^2	Q_e	K_1	R^2	Q_e	K_2	R^2
CK	69.31	-0.0170	0.12	69.31	0.00244	0.12	69.31	0.000036	0.12
UF	70.40	0.0897	0.83	70.41	0.00123	0.82	70.42	- 0.000017	0.81
BF	71.07	0.0043	0.01	71.06	0.00006	0.01	71.05	- 0.000001	0.01
RUF	70.99	0.1293	0.99	71.06	0.00170	0.99	71.13	- 0.000020	0.99
RUBF	73.11	0.1124	0.89	73.19	0.00145	0.99	73.26	-.000019	0.90

Control without fertilization= (CK), 50% Urea formaldehyde fertilizer= (UF), Bio-fertilizer= (BF), 50% Rabbit manure + 50% Urea formaldehyde = (RUF) and 50% Rabbit manure + 50% Urea formaldehyde + Bio-fertilizer= (RUBF).

Table 5. Kinetic parameters and R^2 of the Pseudo-second order, Power function and Parabolic diffusion equations describing the kinetic of nitrogen release.

Treatments	Pseudo-second order			Power function			Parabolic diffusion	
	Q_{e-2}	K'_2	R^2	A	B	R^2	k_p	R^2
CK	60.76	- 0.0336	0.99	- 0.0014	60.91	0.01	- 0.1114	0.05
UF	70.59	0.0196	1.00	0.0333	60.58	0.97	0.9827	0.91
BF	70.06	- 0.0469	0.99	0.0066	60.97	0.11	0.1209	0.04
RUF	70.96	0.0101	0.99	0.0421	60.56	0.96	1.3491	0.99
RUBF	80.12	0.0094	0.99	0.0318	60.92	0.70	1.1132	0.80

Control without fertilization= (CK), 50% Urea formaldehyde fertilizer= (UF), Bio-fertilizer= (BF), 50% Rabbit manure + 50% Urea formaldehyde = (RUF) and 50% Rabbit manure + 50% Urea formaldehyde + Bio-fertilizer= (RUBF).

3.3 Phosphorus kinetics and its release

The effect of fertilizer types on the cumulative P release was also a matter of study herein (Fig.7). Also, the data indicated that the cumulative P release values were increased in all treatments under different incubation periods. The amount of cumulative P release from RUBF treatment was the highest one during all incubation periods compared to other treatments. The cumulative P release ranged from 5.99 to 8.79 and from 5.92 to 7.38 mg kg^{-1} for RUBF and RUF treatments respectively, under incubation periods. The lowest values were observed in incubation period of 2 days, while it began to gradually increase with time for all treatments. Several kinetic equations (Tables 6 and 7) were employed to explain how phosphorus was released into the soil. Under the influence of different treatments in this experiment, since these kinetic equations are most. second-order, pseudo-second order, power function, and zero). In general, all models fit the describe release phosphorus kinetic quite well, depending on the measures associated with each equation. frequently used to describe phosphorous release in the soil.

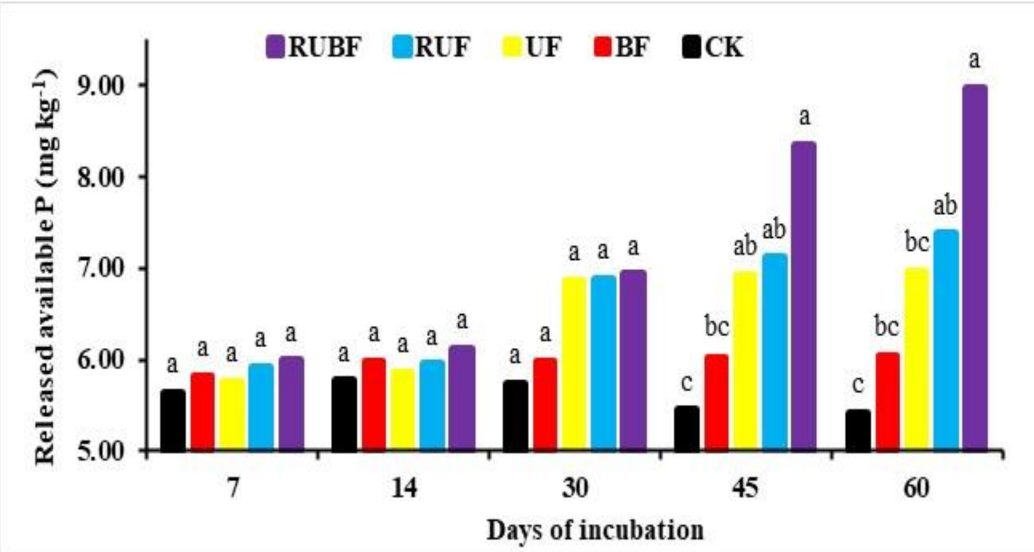

Fig. 7. Effect of fertilizer types on cumulative P during the incubation periods.

Control without fertilization= (CK), 50% Urea formaldehyde fertilizer= (UF), Bio-fertilizer= (BF), 50% Rabbit manure + 50% Urea formaldehyde = (RUF) and 50% Rabbit manure + 50% Urea formaldehyde + Bio-fertilizer= (RUBF). The same letter indicates insignificant difference according to Duncan's test at $p < 0.05$.

The values of (R^2) factor determine which model is the most suited for the provided data. The results indicate that the Pseudo-second order equation is the best and most effective kinetic equation for explaining soil P release (R^2= 0.99-1.00) followed by Zero, First, Second order (R^2=0.64-0.98), Parabolic diffusion (R^2= 0.55- 0.95) and Power function (R^2= 0.43-0.93). According to the parameters of phosphorus kinetic equations in Table (6 and 7) the release of phosphorus from UF, RUF, and RUBF follows a pseudo-second order, with kinetic constants (k) of 0.0588, 0.0404, and 0.0132, respectively. As shown in (Fig. 7), our findings validate a quick release of phosphorus from these fertilizers into the soil. Similarly, the release constants for parabolic diffusion equation (k_p) and power function (a & b), varied with fertilizer types treatments compared to CK treatment. Parabolic diffusion constant (k_p) and power function constant (a) showed linear increase with fertilizer types addition.

Table 6. Kinetic parameters and R^2 of the Zero, First and Second-order describing the kinetic of phosphorus release.

Treatments	Zero-order			First-order			Second-order		
	Q_e	K_0	R^2	Q_e	K_1	R^2	Q_e	K_2	R^2
CK	5.7912	- 0.0059	0.64	5.7935	- 0.0011	0.65	5.7960	0.00019	0.65
UF	5.7014	0.0251	0.81	5.7136	0.0039	0.80	5.7239	- 0.00062	0.80
BF	5.8697	0.0035	0.68	5.8696	0.0006	0.68	5.8695	- 0.00009	0.68
RUF	5.7180	0.0299	0.93	5.7498	0.0045	0.92	5.7756	- 0.0007	0.91
RUBF	5.3885	0.0604	0.98	5.5526	0.0082	0.98	5.6650	- 0.0011	0.98

Control without fertilization= (CK), 50% Urea formaldehyde fertilizer= (UF), Bio-fertilizer= (BF), 50% Rabbit manure + 50% Urea formaldehyde = (RUF) and 50% Rabbit manure + 50% Urea formaldehyde + Bio-fertilizer= (RUBF).

Table 7. Kinetic parameters and R^2 of the Pseudo-second order, Power function and Parabolic diffusion equations describing the kinetic of phosphorus release.

Treatments	Pseudo-second order			Power function			Parabolic diffusion	
	Q_{e-2}	K'_2	R^2	A	B	R^2	k_p	R^2
CK	5.37	- 0.2046	0.99	- 0.0213	6.00	0.43	- 0.0567	0.55
UF	7.27	0.0588	0.99	0.1032	4.56	0.89	0.2724	0.87
BF	6.08	0.5426	1.00	0.0161	5.68	0.85	0.0382	0.77
RUF	7.70	0.0404	0.99	0.1128	4.63	0.93	0.3154	0.95
RUBF	9.80	0.0132	0.98	0.1940	3.88	0.88	0.6187	0.94

Control without fertilization= (CK), 50% Urea formaldehyde fertilizer= (UF), Bio-fertilizer= (BF), 50% Rabbit manure + 50% Urea formaldehyde = (RUF) and 50% Rabbit manure + 50% Urea formaldehyde + Bio-fertilizer= (RUBF).

3.4 Effect of fertilizer types on plant growth and nutrient uptake

As shown in Table (8), it could be noticed that the application of RUBF mostly improved the values of dry weight and plant height over control in cases throughout the experimental period, which increased by 131.67 and 40.91% respectively on black cumin plants. The second rank was occupied by treatment RUF which recorded less weight than RUBF with significant differences which increased by 108.33 and 26.45 to dry weight and plant height respectively over control. On the other hand, the utmost high values of the stem diameter were shown at treatments RUF and RUBF which increased by 42.31 and 11.54 % compared to control. It is evident from data recorded in Fig (8), that all treatments significantly affected the nutrient uptake of black cumin plants. The highest uptake of nitrogen, phosphorus, and potassium were obtained at RUBF treatment which increased by 175.77, 98.08 and 158.91% respectively over the control. On the other hand, the lowest uptake of the aforementioned constituents was mostly gained by UF and BF treatments.

3.5 Effect of applied fertilizers on photosynthesis

Data in (Fig.9) showed the impact of rabbit manure alone or with urea formaldehyde with or without bio-fertilizer on chlorophyll a, b, and carotenoids ratio in black cumin plants. The addition of RUBF significantly enhanced the leaf chlorophyll content ($p < 0.05$) by 28.87, 39.08 and 45.02%, respectively, compared to the control. The impact of fertilizers on chlorophyll a, b, and carotenoids content could be arranged in descending order of RUBF > RUF > UF > BF > CK treatment.

Table 8. Effect of rabbit manure, chemical fertilizer, and or bio-fertilizer on some growth parameters of black cumin plants.

Treatments	Dry weight (g plant^{-1})	Plant height (cm)	Stem diameter
CK	20.00b	80.67d	0.87b
UF	25.00b	88.00cd	0.97b
BF	36.33a	95.00bc	1.30a
RUF	41.67a	102.00b	1.23a
RUBF	46.33a	113.67a	0.97b

Control without fertilization= (CK), 50% Urea formaldehyde fertilizer= (UF), Bio-fertilizer= (BF), 50% Rabbit manure + 50% Urea formaldehyde = (RUF) and 50% Rabbit manure + 50% Urea formaldehyde + Bio-fertilizer= (RUBF). The same letter indicates insignificant difference according to Duncan's test at $p < 0.05$.

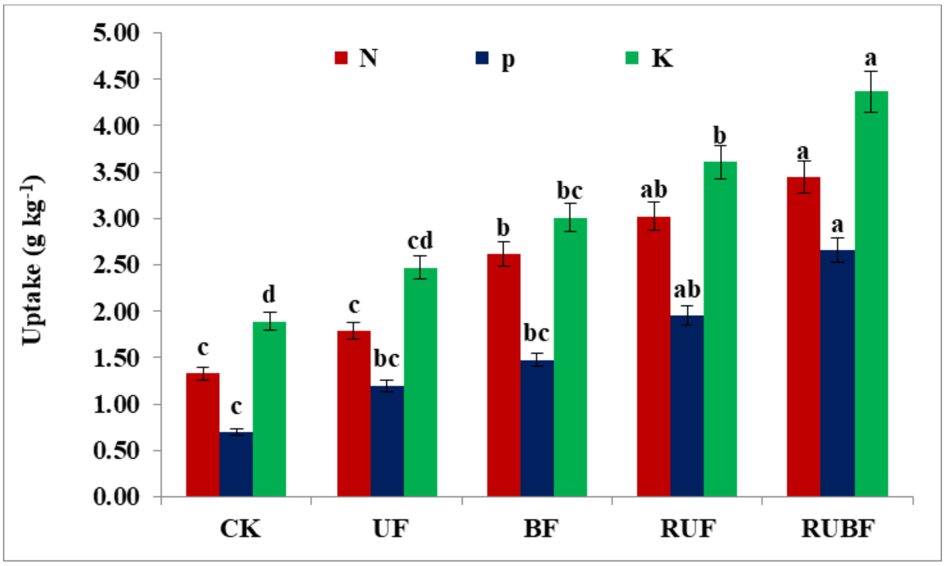

Fig. 8. Effect of rabbit manure, chemical fertilizer, and/or bio-fertilizer on nutrient uptake of black cumin plants.

Control without fertilization= (CK), 50% Urea formaldehyde fertilizer= (UF), Bio-fertilizer= (BF), 50% Rabbit manure + 50% Urea formaldehyde = (RUF) and 50% Rabbit manure + 50% Urea formaldehyde + Bio-fertilizer= (RUBF). The same letter indicates insignificant difference according to Duncan's test at $p < 0.05$.

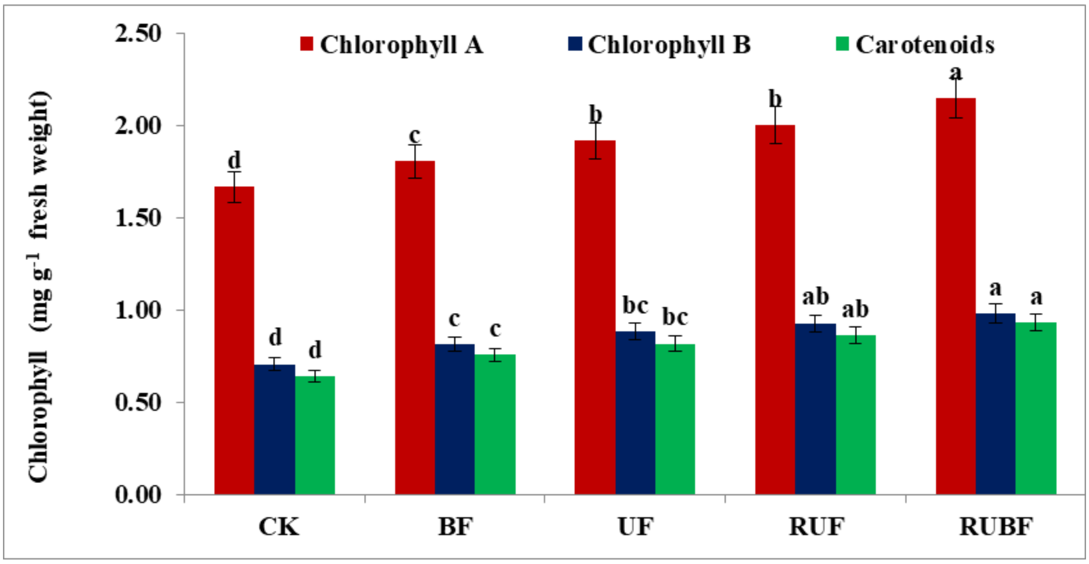

Fig. 9. Effect of rabbit manure, chemical fertilizer, and/or bio-fertilizer on photosynthesis of black cumin plants.

Control without fertilization= (CK), 50% Urea formaldehyde fertilizer= (UF), Bio-fertilizer= (BF), 50% Rabbit manure + 50% Urea formaldehyde = (RUF) and 50% Rabbit manure + 50% Urea formaldehyde + Bio-fertilizer= (RUBF). The same letter indicates insignificant difference according to Duncan's test at $p < 0.05$.

3.6 Effect of applied fertilizers on yield parameters

Our results showed that yield parameters (dry weight capsule, number of capsules and seed weight) increased significantly with the soils amended by rabbit manure + urea formaldehyde + bio-fertilizer (RUBF) as compared to other treatments (Table 9). The highest values were of the dry weight capsules, number of capsules, and seed weight for RUBF treatment, which increased by 27.40, 101.67, and 34.47% respectively, compared with control (CK) treatment. The dry weight capsules, number of capsules, and seed weight followed the descending order of RUF > RUF > BF > UF > CK treatments.

Table 9. Effect of rabbit manure, chemical fertilizer, and/or bio-fertilizer on some yield parameters of black cumin plants.

Treatments	Dry weight capsule (g plant^{-1})	Number of capsules	Seed weight (g plant $^{-1}$)
CK	17.40d	36.87d	10.67c
UF	21.20cd	58.67c	14.27c
BF	25.20bc	74.73b	21.27b
RUF	29.33ab	78.00b	24.47ab
RUBF	34.47a	101.67a	27.40a

Control without fertilization= (CK), 50% Urea formaldehyde fertilizer= (UF), Bio-fertilizer= (BF), 50% Rabbit manure + 50% Urea formaldehyde = (RUF) and 50% Rabbit manure + 50% Urea formaldehyde + Bio-fertilizer= (RUBF). The same letter indicates insignificant difference according to Duncan's test at $p < 0.05$.

4. Discussion

4.1 Soil properties

Fertilizers addition considerably enhanced tested soil chemical properties, i.e. pH, EC, and SOM of the soil. Substantial decrease in soil pH was noticed as the time proceeded for all treatments. In this concern, the highest reductions were recorded for RUBF treatment. The decrease of soil pH was more pronounced with addition of RUBF treatment. The decrease in soil pH may be due to the increased microbial activity in release of organic acids and carbon dioxide, these organic acids (cysteine, humic acid, amino acid, and glycine) are formed during the mineralization of organic materials (ammonization and ammonification) by heterotrophs and nitrification (autotrophs) are responsible for the soil pH decrease, these results are agreement with those obtained by (Adekiya et al., 2019; Zhang et al., 2023;). After two months of incubation, rabbit manure and urea formaldehyde, either with or without bio-fertilizer, were caused lower soil acidity in a way that differed than the control treatment (Al-Sayed et al., 2024). Moreover, the soil pH was decreased by the application of rabbit manure due to the production of organic acids during the mineralization of organic manure (Youssef and Eissa, 2017). Adding rabbit manure and ureaform without or with bio-fertilizers to the soil induces increases in soil EC compared to CK control, these fertilizers high concentration of salt may be the cause of the soil's high EC values and the release of dissolved salts from it after addition to soil. The electrical conductivity increased owing to both organic and chemical fertilizer application (Yaganoglu and Aydin, 2024). El-Mogy et al., (2020) reported that rabbit manure fertilizer increased soil EC compared to chemical fertilization. Compost + bio-fertilizer increased electrical conductivity by 10.9 % compared to the non-amended control during the incubation period (Al-Sayed et al., 2022). The data demonstrated that amount of organic matter increased as result applying different fertilizer compared to the unamended control.

Organic fertilizer combined with chemical fertilizer can provide a timely replenishment of available nutrients, compared with only chemical fertilizer input. Consequently, combination of chemical fertilizer and organic fertilizer may provide sufficient nutrient substrates and energy for microorganisms, even with slow decomposition of organic fertilizer, resulting in the higher OM content (Li et al., 2022). This organic matter served as a substrate for microorganisms that may have played a vital role in breaking down complex compounds, organic manure may have introduced a diverse array of beneficial microorganisms to the soil and may have contributed to increased soil organic carbon (Elsherpiny et al. 2023; Elbaalawy et al. 2023). These results corroborate the findings of Adekiya et. al., (2020) discovered that rabbit manure increased soil organic matter compared to organic manures other, this increase in organic matter of rabbit manure may be related to its high C/N ratio and lignin amount. Zhang et al., (2022) found that the organic matter (OM) was significantly increased by 13.30 to 40.56%, with increasing amounts of organic manure.

4.2 Nitrogen release and its kinetics

Addition of organic, chemical and bio-fertilizers significantly affected available nitrogen. The results obtained herein showed that the highest value of available nitrogen concentration was observed in RUBF treated soil, which was 80.78 g kg^{-1} after 60 days from incubation. It is anticipated that the breakdown of organic fertilizers will reduce soil acidity, promote soil microbial activity, improve plant nutrient availability, and accelerate the release of nitrogen from the acid-soluble pool. These results corroborate the findings of this could be the result of

(Yousef et al., 2023). Also, nitrogen availability may have increased as a result of increased bacterial nitrogen fixation and increased native soil nitrogen by the microorganisms in the bio-fertilizer (Almaroai and Eissa, 2020). Kalita et al (2023) found that the available nitrogen increased by 26.47% and 24.17% with application of pig manure and poultry respectively, over control. According to Sathish et al. (2011), applying organic manures and mineral nitrogen together raises the amount of nitrogen in the soil.

The kinetics of nitrogen releases from different fertilizer types conform to the Pseudo-second order kinetics, while second-order kinetics shows the immobilization of nitrogen, because the constant (k_2) has negative values, meaning that not a lot of nitrogen is released, which is consistent with Kong et al (2020) stated that the Pseudo-first-order kinetic models give better outcomes. Kalita et al (2023) found that the nitrogen release from different organic sources conform to the first-order kinetics. It is obvious that the nitrogen release was slower from BF treatment than UF, RUF and RUBF treatments, this may be due to a mineral nitrogen addition in form urea formaldehyde, allowing the majority of the nitrogen to be released straight from these treatments. Also, using ureaform in combination with bio and organic fertilizer increased the N availability compared to that of other treatments. Maybe du that the presence of organic fertilizer with bio-fertilizer activated the soil microorganisms causing an increase in the activity of soil enzymes and an improvement in the availability of essential nutrients (Abd Allah Azab et al., 2024; Kumar et al.2022; Martin et al., 2024).

4.3 Phosphorus release and its kinetics

The addition of chemical, organic and bio-fertilizers raised the amount of phosphorus available compared with the control. Among of these treatments, RUBF had the highest values of phosphorus. This increases could be because those soils receiving organic matter alone or in combination with mineral nitrogen improved the organic carbon, phosphorus content. Also, as a result of mineralization process of organic matter. Also, the respiration of heterophylic bacteria (Azotobacter and Azospirillum) produced carbon dioxide that solved in soil solution formed carbonic acid that help to release some nutrient from insoluble minerals. All organic sources (rabbit manure, poultry manure and green manure) and NPK fertilizer of soil amendment increased P significantly ($p < 0.05$) with respect to the control (Adekiya et. al., 2020). Application of both organic and chemical fertilizers led to a significant increase in the available phosphorus content in soil (Yaganoglu and Aydin, 2024). Organic fertilizer may have contributed to improved soil structure and water retention helping to maintain a more favorable pH range for phosphorus availability (Farid et al., 2023; Elshaboury et al. 2024). The positive influence of rabbit manure on soil nutrient availability can be attributed to multiple mechanisms. rabbit manure likely had a higher nutrient content, providing an enriched source of (N, P, and K) to the soil which is inherently rich in essential nutrients. This can be attributed to organic composts harboring beneficial microorganisms contributing to nutrient cycling and mineralization (Biratu et al., 2018).

In this experiment, the six models all rather well depict the variability in release phosphorus kinetics. The model appropriateness for the given data is determined by the determination factor (R^2) value, which is based on the measures associated with each equation. Among various equations, the pseudo-second order is the one that most accurately describes the release phosphorus. The equation of the pseudo-second order equation, has explained the release of phosphorus in the soil from all treatments, these fertilizers play a vital role in this process. As well the released amount from p depends on the time factor, it is directly proportional to time. The results revealed that the high values of (K_2) of the pseudo-second order for all treatments compared to the control treatment indicates that the amount released from P is high and may meet the plant's need at the stages where the plants need is high (Etesami 2020). According to Lyu et al. (2020), the equations of pseudo-second order could better describe the kinetics of the available phosphorus release process in each manure treatments, followed by power function equation, whereas the parabolic equation performed poorly in terms of fitting. Habeeb et al (2023) reported that the equations (first order and power function) unequivocally demonstrate that the concentration, quantity, and the temporal variables of phosphorus all affect how much phosphorus is released into the soil solution and how well it may be absorbed by the plant.

4.4 Growth and parameters of black cumin

In the present study, addition of chemical, organic, and bio-fertilizers increased growth parameters, nutrient uptake, photosynthesis and yield parameters of black cumin compared with the control. Among different amendment applied, 50% Rabbit manure + 50% urea formaldehyde + bio-fertilizer (RUBF) had the highest values of these studied parameters. This improvement may be related to the significantly higher nitrogen accumulation and nitrogen use efficiency (Zhao et al., 2024). Along with being essential for the formation of proteins, amino acids, chlorophyll, and nucleic acids, nitrogen also controls a variety of chemical reactions that take place in plant cells and aids in the movement of electrons (Gupta et al., 2024; Martin et al., 2024).

Numerous studies have demonstrated that organic additives enhance the growth of microorganisms, which in turn improve nutrient uptake by lengthening root growth, which increasing growth parameters and causes soil nutrient sources to become more soluble. Additionally, microorganisms promote the manufacture of phytohormones in the rhizosphere, including auxins, various amino acids, antibiotics, hydrogen cyanide, and siderophores, all of which ultimately enhance development (Al-Sayed et al., 2023). Azotobacter, and Azospirillum were used to inoculated black cumin plant and their height, number of branches, and capsules were increased significantly (Moradzadeh et al., 2021). Additionally, by combining bio-fertilizers with chemical and organic fertilizers, more nutrients can be provided, which increases seed weight, improves photosynthetic capacity through bacterial secretions and pH regulation, and effectively boosts output by producing more assimilates (Alami Milani et al., 2015; Kour et al., 2019). When combined with minimal amounts of chemicals, bio-fertilizer improved growth more than when applied alone with chemical fertilizer, organic manure and bio-fertilizer (Zainuddin et al., 2022).

It's important to note that adding bio-fertilizers in the presence of rabbit manure increased the microbial biomass in the soil, which in turn increased their effectiveness in improving the growth of plants, root development and increases nutrient uptake by plants via the production of growth-promoting compounds like cytokinins, indole acetic acid, gibberellins (Saharan and Nehra, 2011; Elbagory, 2023; Mosaad et al., 2024 and Rashwan et al., 2024). These results are in harmony with those obtained by (Sarhan and Bashandy, 2021; Gupta,et al. 2024) who reported that the bio-fertilizer, revealed that, using Azotobacter and Azospirillum as a bio-fertilizer gave highest N, P, and K concentration than without bio-fertilizer treatment.

5. Conclusions

Application of rabbit manure, urea formaldehyde and bio-fertilizer were most effective in improvement in soil as evidenced by changes in properties like pH, EC, availability nitrogen, phosphorus and organic matter content. The rabbit manure and urea formaldehyde considered a slow-release N and P sources, therefore the combination of these fertilizers contributed to an increased the N and P released. Relatively, compared to other treatments. Furthermore, an excellent idea for assessing the fitting of six kinetic equations is these fertilizers; The best equation to describe the release of nitrogen and phosphorus from soils was pseudo-second order, which produced a better correlation coefficient. Also, black cumin plant vegetative growth, yield and development were all favourably impacted by the addition of rabbit, urea formaldehyde, and bio-fertilizer together, from between five treatments, the best treatment (RUBF) was that gives the greatest increase in growth metrics, NPK uptake, yield parameters and photosynthetic pigments (chlorophyll a and b) by black cumin plants. We may conclude that combining rabbit manure, urea formaldehyde, and bio-fertilizer improves plant growth, soil fertility, N and P release.

Author Contributions: All authors contributed significantly and equally to the conceptualization, writing, editing, and review of the current manuscript. All authors agreed to the submission of the current manuscript.

Statements and Declarations: On behalf of all authors, the corresponding author states that there is no conflict of interest.

Funding: This research received no external funding.

6. References

Abdu, N., (2013). Formulation of a first-order kinetic model and release of added phosphorus in a savanna soil. Archives of Agronomy and Soil Sciences, 59: 71–81.

Adekiya, A. O., Agbede, T. M., Aboyeji, C. M., Dunsin, O., & Ugbe, J. O., (2019). Green manures and NPK fertilizer effects on soil properties, growth, yield, mineral and vitamin C composition of okra (*Abelmoschus esculentus* (L.) Moench). *Journal of the Saudi Society of Agricultural Sciences,* 18 (2), 218-223.

Adekiya, A. O., Ejue, W. S., Olayanju, A., Dunsin, O., Aboyeji, C. M., Aremu, C., Adegbite, K., & Akinpelu, O., (2020). Sources and NPK fertilizer on soil chemical properties, growth, yield and quality of okra. *Scientific Reports*, 10:16083.

Alami Milani, M., Amini, R., and Bandehagh, A. (2015). Effect of bio-fertilizers and combination with chemical fertilizers on grain yield and yield components of pinto bean (*Phaseolus vulgaris* L.). *Journal of Agricultural Science and Sustainable Production*, *24*(4.1), 15-29.

Ahmad, A., Husain, A., Mujeeb, M., Shah Khan, A., Najmi, A. K., Siddique, N. A., Damanhouri, Z. A., & Anwar, F., (2013). A review on therapeutic potential of *Nigella sativa*: A miracle herb. *Asian Pacific Journal of Tropical Biomedicine*, 3(5), 337-352.

Almaroai, Y. A., & Eissa, M. A. (2020). Role of marine algae extracts in water stress resistance of onion under semiarid conditions. *Journal of Soil Science and Plant Nutrition*, 20(3), 1092-1101.

Al-Sayed, H. M., Ali, A. M., & Khalafalla, M. Y. (2024). Carbon Mineralization Kinetics and Soil Fertility Induced by Organic and Bio-Fertilization Through Different Incubation Periods. *Communications in Soil Science and Plant Analysis*, 55(8), 1159-1174.

Al-Sayed, H. M., Hegab, S. A., Youssef, M. A., Khalafalla, M. Y., & Eissa, M. A., (2022). Compost and non-symbiotic nitrogen fixers to reduce inorganic-N rates for roselle (*Hibiscus sabdariffa* L.). *Communications in Soil Science and Plant Analysis*, 54 (3), 431-443.

Al-Sayed, H. M., Khalafalla, M. Y., & Ali, A. M. (2023). Effects of compost and bio-fertilizer on carbon dioxide emission, yield, and quality of roselle (*Hibiscus sabdariffa* L.) plants grown on clay loam. Journal of Plant Nutrition, 46 (11), 2707-2723.

Azab, M.A., Ali, A. M., M. EL-Sayed, M., Yousef, A. F., and Al-Sayed, H. M. (2024). Irrigation regime with organic and bio-fertilizers for faba bean production grown on sand clay loam soil. *Journal of Plant Nutrition*, 1-14. https://doi.org/10.1080/01904167.2024.2338770

Biratu, G. K., Elias, E., Ntawuruhunga, P., & Nhamo, N. (2018). Effect of chicken manure application on cassava biomass and root yields in two agro-ecologies of Zambia. Agriculture, 8(4), 45.

Chalk, P. M., Craswell, E. T., Polidoro, J. C., & Chen, D., (2015). Fate and efficiency of 15 N-labelled slow-and controlled-release fertilizers. *Nutrient Cycling in Agroecosystems*, 102, 167-178.

Darakeh, S. A. S. S., Weisany, W., Tahir, N. A. R., & Schenk, P. M., (2022). Physiological and biochemical responses of black cumin to vermicompost and plant biostimulants: Arbuscular mycorrhizal and plant growth-promoting rhizobacteria. *Industrial Crops and Products*, 188, 115557.

Elbaalawy, A. M., Tantawy, M. F., Abd Elhafez, E., & Nada, W. M. (2023). Sulphur compost properties and its amelioration effect on salt affected soil characteristics and productivity. *Egyptian Journal of Soil Science*, 63(3), 339-354.

Elbagory, M., (2023). Reducing the adverse effects of salt stress by utilizing compost tea and effective microorganisms to enhance the growth and yield of wheat (*Triticum aestivum* L.) plants. *Agronomy*, 13 (3), 823.

El-Beltagi, H. S., Nada, R. S., Mady, E., Ashmawi, A. E., Gashash, E. A., Elateeq, A. A., Suliman, A. A., Harbi, N. A., Al-Qahtani, S. M., Zarad, M. M., & Randhir, T. O., (2023). Effect of organic and bio-fertilization on fruit yield, bioactive constituents, and estragole content in fennel fruits. *Agronomy* 13(5), 1189; https://doi.org/10.3390/agronomy13051189

El-Mogy, M. M., Abdelaziz, S. M., Mahmoud, A. W. M., Elsayed, T. R., Abdel-Kader, N. H., & Mohamed, M. I. A., (2020). Comparative effects of different organic and inorganic fertilizers on soil fertility, plant growth, soil microbial community, and storage ability of lettuce. *Agriculture* 66 (3), 87-107.

Elshaboury, H., Ibrahim, N., and Elsherpiny, M. (2024). Enhancing Soybean Productivity in Saline Soil Conditions: Synergistic Effects of Organic Fertilizer and Proline Co-Application. *Egyptian Journal of Soil Science,* 64(2), 385-395.

Elsherpiny, M. A., ElGhamry, A., GHAZI, D. A., Soliman, M., and Helmy, A. (2022). Titanium: An element of non-biological atmospheric nitrogen fixation and a regulator of sugar beet plant tolerance to salinity. *Egyptian Journal of Soil Science*, 62(4), 373–381.

Etesami, H., (2020). Enhanced phosphorus fertilizer use efficiency with microorganisms. *Nutrient dynamics for sustainable crop production.* Springer, Singapore, 215-245.

Farid, I. M., Abbas, M. H. H., and El-Ghozoli, A. (2023). Wheat productivity as influenced by integrated mineral, organic and biofertilization. *Egyptian Journal of Soil Science*, 63(3), 287–299.

Gupta, M., Sharma, R., Sharma, M., Sharma, S., & Sharma, P. (2024). Influence of inorganic fertilizers with biofertilizers on biochemical components, growth and yield of garlic under subtropical irrigated condition. *Journal of Plant Nutrition*, 47(6), 837-849.

Grzyb, A., Wolna-Maruwka, A., & Niewiadomska, A., (2020). Environmental factors affecting the mineralization of crop residues. *Agronomy*, 10 (12), 1951.

Habeeb, K. H., Odhafa, A. K. H., & Kareem, H. H., (2023). Effect of different types and levels of phosphorous fertilizers on kinetics of phosphorous release in the soil. *Revis Bionatura* 8 (2), 11.

He, H., Peng, M., Hou, Z., & Li, J., (2024). Organic amendment substitution improves the sustainability of wheat fields changed from cotton and vegetable fields. *Agriculture, Ecosystems & Environment,* 359, 108769.

He, X., Augusto, L., Goll, D. S., Ringeval, B., Wang, Y. P., Helfenstein, J., & Hou, E., (2023). Global patterns and drivers of phosphorus fractions in natural soils. *Biogeosciences*, 20 (19), 4147-4163.

Helfenstein, J., Pistocchi, C., Oberson, A., Tamburini, F., Goll, D. S., & Frossard, E., (2020). Estimates of mean residence times of phosphorus in commonly considered inorganic soil phosphorus pools. *Biogeosciences*, 17 (2), 441-454.

Ikrarwati Syamsi, N. A., Sastro, Y., Rusbana, T. B., Sudolar, N. R., & Romadhonah, Y., (2021). Quality of growth media and yields of Allium ascolanicum L. on ultisol soil combined with rabbit manure. IOP Conference Series: *Earth and Environmental Scienc*e, 715(1), 012039.

Jackson, M. L., (1973). Soil chemical analysis. Englewood Cliffs, NJ: Prentice Hall. Inc. Englewood Cliffs, N. J. New Delhi, India.

Kalita, L., Singh, N. J., Ray, L. I., & Singh, A. K., (2023). Incubation study of kinetics and mineralization rate of nitrogen in organic sources of Ultisol. *Current Science*, 125 (7), 765-770.

Khosropour, E., Weisany, W., Tahir, N. A. R., & Hakimi, L., (2022). Vermicompost and biochar can alleviate cadmium stress through minimizing its uptake and optimizing biochemical properties in Berberis integerrima bunge. *Environmental Science and Pollution Research*, 29 (12), 17476-17486.

Klute, A., (1986). Methods of Soil Analysis. Part 1: Physical and mineralogical methods (2nd edition). A. Soc. of A gronomy Inc., Madison, Wisconsin, USA.

Kong, W., Huang, S., Shi, F., Yang, Z., Feng, Y., Khatoon, Z., & Xiao, Y., (2020). Study on release kinetics of nitrogen and phosphorus from fish feed. *Aquaculture research*, 51(8), 3216-3229.

Kour, D., Wali, V. K., Bakshi, P., Bhat, D. J., Sharma, B. C., Sharma, V., & Sinha, B. K., (2019). Effect of integrated nutrient management strategies on nutrient status and soil microbial population in Aonla (Emblica officinalis Gaertn.) Cv. Na-7. *International Journal of Current Microbiology and Applied Sciences*, 8, 1272-1281.

Kumar, P., Dubey, S. D., Sachan, R., Rawat, C. L., & Kumar, V. (2022). Effect of organic manure, inorganic fertilizers and biofertilizers on nutrient content of maize (*Zea mays* L.) and their residual effect on succeeding wheat (*Triticum aestivum* L.) crop. Int J Plant Soil Sci, 34(20), 817-27.

Li, R., Wang, H., Duan, E., Fan, J. & Wang, L., (2022). Rabbit manure compost for seedling nursery blocks: Suitability and optimization of the manufacturing production process. *Agriculture* 12 (12), 2156.

Lichtenthaler, H. K., (1987). Chlorophylls and carotenoids pigments of photosynthetic bio membranes in Methods in Enzymology, 148, 183-350.

Lyu, J., Gao W., Hao, X., Zhang, R., Zhang, B., & Xue, Y., (2020). Study of phosphorus mineralization characteristics in a mine reclaimed soil under different organic fertilizers. icle: *Journal of Irrigation and Drainage*, 39 (4), 59-67.

Martin, T. N., Monçon Fipke, G., Maria Müller, T., Cechin, J., Faé, G. S., & Almeida Arismendi, G. (2024). *Azospirillum brasilense*: Inoculation and Nitrogen Management on the Development and Yield of Barley. *Communications in Soil Science and Plant Analysis*, 55(8), 1148-1158.

Moghaddam, H. K., Banihabib, M. E., Javadi, S., & Randhir, T. O., (2021). A framework for the assessment of qualitative and quantitative sustainable development of groundwater system. *Sustainable Development*, 29 (6), 1096-1110.

Moradzadeh, S., Siavash Moghaddam, S., Rahimi, A., Pourakbar, L., & Sayyed, R. Z., (2021). Combined bio-chemical fertilizers ameliorate agro-biochemical attributes of black cumin (*Nigella sativa* L.). *Scientific Reports*, 11 (1), 11399.

Mosaad, I. S., Gaafar, D. E., Al-Anoos, M. A., & Seadh, A. K., (2024). Synergistic Effects of Plant Growth Promoting Rhizobacteria and Mycorrhizal Fungi on Roselle Performance in Sandy Soils. *Egyptian Journal of Soil Science*, 64 (2), 443-457.

Murugan, A. V., & Swarnam, T. P., (2013). Nitrogen release pattern from organic manures applied to an acid soil. Canadian Center of Science and Education. *Journal of Agricultural Science*, 5 (6), 174-84.

Nasiroleslami, E., Mozafari, H., Sadeghi-Shoae, M., Habibi, D., & Sani, B., (2021). Changes in yield, protein, minerals, and fatty acid profile of wheat (*Triticum aestivum* L.) under fertilizer management involving application of nitrogen, humic acid, and seaweed extract. *Journal of Soil Science and Plant Nutrition*, 21 (4), 2642-2651.

Ranjbar, F., & Jalali, M., (2014). Empirical and mechanistic evaluation of NH4+-N release kinetic in calcareous soils. *Archives of Environment Contamination and Toxicology*, 66, 606-615.

Rashwan, B., El-Azazy, H., & Mahmoud, R., (2024). Impact of cultivation methods and fertilization by EM (Effective microorganisms) and/or compost on Productivity and water use efficiency of wheat (*Triticum aestivum* L.). *Egyptian Journal of Soil Science*, 64 (1), 83-98.

Saharan, B. S., & Nehra, V., (2011). Plant growth promoting rhizobacteria: a critical review. The *International Journal of Life Science and Medical Research*, 21 (1), 30.

Sarhan, M. G., & Bashandy, S., (2021). Enhancing onion yield, quality, storability and profitability by using FYM, copper and bio-fertilizer. *Egyptian Journal of Soil Science*, 61 (3), 323-335.

Sathish, A., Govinda, G. V., Chandrappa, H., & Nagaraja, K., (2011). Long term effect of integrated use of organic and inorganic fertilizers on productivity, soil fertility and uptake of nutrients in rice and maize cropping system. *International Journal of Science and Nature*, 2 (1), 84-88.

Sarhan, M. G., & Bashandy, S., (2021). enhancing onion yield, quality, storability and profitability by using FYM, copper and bio-fertilizer. *Egyptian Journal of Soil Science*, 61 (3), 323-335.

Shaji, H., Chandran, V., & Mathew, L., (2021). Chapter 13 - Organic fertilizers as a route to controlled release of nutrients. In: Lewu F.B., Volova T., Thomas S., K. R. R., (eds) Controlled Release Fertilizers for Sustainable Agriculture. *Academic Press*, 231-245.

Song, D.L., Hou, S.P., Wang, X.B., Liang, G.Q. & Zhou, W., (2018). Nutrient resource quantity of animal manure and its utilization potential in China. *Journal of Plant Nutrition and Fertilizers*, 24 (5), 1131-1148.

Sparks, D. L., Page, A. L., Helmke, P. A., & Loeppert, R. H. (Eds.). (2020). Methods of soil analysis, part 3: Chemical methods (Vol. 14). John Wiley & Sons.

Steel, R. G. D and Torrie, J. H. (1986). Principle and Procedure of statistics. A Biometrical Approach: 2 ed., McGraw- Hill Book Co. New York.

Tembhurne, S. V., Feroz, S., More, B. H., & Sakarkar, D. M., (2014). A review on therapeutic potential of *Nigella sativa* (kalonji) seeds. Journal of medicinal plants research, 8 (3), 167-177.

Toor, G. S., & Bahl, G. S., (1999). Kinetics of phosphate desorption from different soils as influenced by application of poultry manure and fertilizer phosphorus and its uptake by soybean. *Bioresource Technolm*, 69 (2), 117-121.

Wu, H., Hao, H., Lei, H., Ge, Y., Shi, H., & Song, Y., (2021). Farm size, risk aversion and overuse of fertilizer: The heterogeneity of large-scale and small-scale wheat farmers in Northern China. *Land*, 10 (2), 111.

Yağanoğlu, E., & Aydin, A. (2024). The effect of organic and chemical fertilizers on the activity of soil enzymes in soils of different compositions. *Turkish Journal of Agriculture and Forestry*, 48(1), 116-128.

Yimer, E. M., Tuem, K. B., Karim, A., Ur-Rehman, N., & Anwar, F. (2019). *Nigella sativa* L. (black cumin): a promising natural remedy for wide range of illnesses. *Evidence-Based Complementary and Alternative Medicine*, 2019.

Yousef, A. F., Ali, A. M., Azab, M. A., Lamlom, S. F., & Al-Sayed, H. M., (2023). Improved plant yield of potato through exogenously applied potassium fertilizer sources and bio-fertilizer. *AMB Express*, 13 (1), 124.

Youssef, M. A., & Eissa, M. A., (2017). Comparison between organic and inorganic nutrition for tomato. *Journal of Plant Nutrition*, 40 (13), 1900-1907.

Zainuddin, N., Keni, M. F., Ibrahim, S. A. S., & Masri, M. M. M., (2022). Effect of integrated bio-fertilizers with chemical fertilizers on the oil palm growth and soil microbial diversity. *Biocatalysis and Agricultural, Biotechnology*, 39, 102237.

Zarcinas, B. A., Cartwright, B., & Spouncer, L. R., (1987). Nitric acid digestion and multi-element analysis of plant material by inductively coupled plasma spectrometry. *Communications in Soil Science and Plant Analysis*, 18 (1), 131-146.

Zhang, C., Zhao, Z., Li, F., & Zhang, J., (2022). Effects of Organic and Inorganic Fertilization on Soil Organic Carbon and Enzymatic Activities. *Agronomy*, 12 (12), 3125.

Zhang, X., Li, J., Shao, L., Qin, F., Yang, J., Gu, H., Zhai, P., & Pan, X., (2023). Effects of organic fertilizers on yield, soil physico-chemical property, soil microbial community diversity and structure of *Brassica rapa* var. Chinensis. *Frontiers in Microbiology*, 14:1132853.

Zhao, T., He, A., Khan, M. N., Yin, Q., Song, S., & Nie, L., (2024). Coupling of reduced inorganic fertilizer with plant-based organic fertilizer as a promising fertilizer management strategy for colored rice in tropical regions. *Journal of Integrative Agriculture*, 23 (1), 93-107.