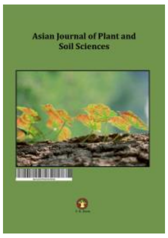

Asian Journal of Plant and Soil Sciences

Volume 9, Issue 1, Page 39-56, 2024; Article no.AJOPSS.12354

Integrated Management of Slow-release Nitrogen Fertilizer Types and Rates for Wheat Production under Middle Nile Delta Soil Conditions

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://prh.ikprress.org/review-history/12354

Original Research Article

Received: 19/06/2024
Accepted: 31/08/2024
Published: 05/09/2024

ABSTRACT

In light of the state's trends towards sustainable agricultural development and achieving self-sufficiency in food, especially wheat, as it is considered a strategic crop in Egypt. Also, in order to preserve the environment and human health as well as save the material and moral losses resulting from the excessive use of urea as a nitrogen fertilizer. So, two field experiments were conducted at the experimental farm of Tag El-Ezz, Agricultural Research Station (30º 59\ N latitude, 31º 58\ E longitude´), ARC, Dakahlia Governorate, Egypt, during two winter successive growing seasons of 2022/2023 and 2023/2024. The experiments evaluated the efficiency of two different mineral slow-release nitrogen fertilizer sources: urea formaldehyde (UF), sulfur coated urea (SCU) and two

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***Cite as:** Faiyad, Riham M. N., and Eman H. Abd El-Azeiz. 2024. "Integrated Management of Slow- Release Nitrogen Fertilizer Types and Rates for Wheat Production under Middle Nile Delta Soil Conditions". Asian Journal of Plant and Soil Sciences 9 (1):39-56. https://journalplantsoil.com/index.php/AJOPSS/article/view/105.*

organic amendments: compost (C) and vermicompost (VC) individually or in combination using different rates comparing with usual fertilizer urea (U) at recommended nitrogen fertilization rate (178.5 kg N ha^{-1}) for wheat production under alluvial soil conditions. As well as, tracking the fate nitrogen in the soil during different wheat growth stages and effect of treatments on some chemical properties of experimental soil after harvesting.

The acquired results demonstrated the ability to apply slow-release nitrogen fertilizers in mineral or organic form to sustain agricultural output and preserve environmental quality. Combination of mineral and organic fertilizers achieved the best growth and improved physiological functions and chlorophyll formation. Combination treatment of urea formaldehyde (UF) 50% of nitrogen recommended dose (NRD) and vermicompost (VC 25% of NRD) (treatment N9) increased vegetative growth parameters and chlorophyll content comparing with the other treatments. Treatment N9 increased chlorophyll a by 4.96 and 4.47% as well as increased chlorophyll b by 3.21and 3.89% in both seasons, respectively comparing with the control treatment (usual urea at 100% NRD).

Application of sulfur coated urea (SCU 50% NRD) in combination with vermicompost (VC 25% NRD) (treatment N11) was the superior treatment application at harvest stage. Treatment N11 increased yield by 11.63 and 11.45% in two successive seasons respectively comparing with the control treatment (N1). Regarding to the soil, all slow-release nitrogen fertilizer treatments had a significant impact on the soil's nitrogen content at various interval phases and on chemical soil properties i.e. pH, Ec and organic matter content.

From an economic point of view, SCU at 50% NRD combined with compost at 25% NRD (N10 treatment) applied treatment listed the highest net return (7807.4 and 24107.4) as well as BCR (1.18 and 1.37) in both growing seasons , respectively . So, it could be an excellent alternative to usual urea for increasing production and farmer revenue.

Finally, the results show that treatments involving the interaction of slow-release fertilizers from both organic and mineral sources have a long-term impact in terms of reducing fertilization rates, increasing wheat productivity, and improving soil properties that have been degraded as a result of agricultural practices. Furthermore, my production and specifications are compliant with food safety requirements and agricultural quarantine regulations for export, which aligns with the state's initiatives to promote sustainable agriculture.

Keywords: Urea; urea formaldehyde; sulfur coated urea; compost; vermicompost; wheat; N efficiency.

1. INTRODUCTION

Wheat (*Triticum aestivum* L.) is a staple crop and a major source of food, energy, protein, and fiber throughout the world, particularly among the third world population [1]. Raising wheat yield is a crucial national objective in order to meet Egypt's growing food demands [2]. In Egypt, Wheat represents about 40% of total cereal production and its production in 2023 is estimated at 9.7 million ton [3]. Dakahlia Governorate is considered one of Egypt's principal agricultural governorates with the cultivated area 683,000 feddan [4]. It is well-known for growing traditional crops like maize, cotton, rice, and wheat [5].

Fertilizers are at the heart of our agricultural society; without them, we would be unable to feed the vast majority of the world's people. Mineral fertilizers supply plants with nutrients such as nitrogen, phosphorous, and potassium in easily absorbed forms. Nitrogen is one of the most critical essential nutrients for good plant growth, and it is frequently given in the form of urea and ammonium salts [6,7]. Urea fertilizer $CO(NH_2)_2$ is a well-known and most widely utilized source of nitrogen as it has a high nitrogen concentration (46.5%). But, more than 30% of urea is lost where it dissolved in the soil water and be available for a short period of time, releasing bicarbonate and ammonia which is lost by decomposition, volatilization, and leaching resulting in environmental contamination [8].

Regulating the emission of nitrogen into the soil solution is the most dependable and effective technique to align nutrient availability with plant requirements. Therefore, Slow-release fertilizers (SRFs) were developed to minimize usual fertilizer losses and enhance fertilizers efficiency [9]. So, they are viewed as an economically viable and eco-friendly alternative to chemical traditional fertilizers.

Mineral slow-release fertilizers (MSRFs) are made up by inorganic materials that covers the soluble fertilizers as sulfur or an organic polymer which inhibit water penetration and control nutrient dissolving rate, thereby controlling nutrient release as plants needed [10]. Urea Formaldehyde (UF) including about 38.50% N is the earliest known class of slow -release nitrogen fertilizers [11]. It is produced through an interaction between urea and formaldehyde under specific parameters such as pH, temperature, molar proportion and reaction duration [12]. Sulfur coated urea (SCU) including 40.22% N and 20% S is manufactured by coating heated urea with molten sulfur, which is a low-cost coating. The quality and thickness of the coating influence N release from SCU particles [13].

Many local and international studies have investigated the effect of slow-release nitrogen fertilizers, which have confirmed their superiority in wheat crop production and nitrogen loss reduction when compared to usual urea. These studies have recommended using slow- release nitrogen fertilizers (SRNFs) as a better environmental and productive alternative to usual urea [14,15,16].

Excessive use of inorganic fertilizers degrades the soil physically, imbalances the nutrients in the soil, reduces soil fertility, and lowers the quality of food produced [17]. While, organic fertilizers have been employed as an alternative solution because they are safer for human health and have a positive impact on soil qualities such as soil structure and soil fertility [18]. Compost (C) and vermicompost (VC) were used as organic slow-release N fertilizers. They are soil conditioners that providing the soil with organic matter and nutrients as well as improving water and nutrient retention [19]. Compost (1.34% N) is an organic material that has been biologically decomposed by thermophilic and mesophilic microorganisms [20], whereas vermicompost (2.40% N) is organic substances that have been broken down by earthworms and microorganisms in a mesophilic process to create organic soil additives that are totally stable [21,22].

The application of both organic and inorganic fertilizers increase the ability of nutrients to meet plant requirements from a variety of sources over longer periods of time and improve nutritional status of plants, which benefit both yield & quality, and also improve soil qualities [23].

So, the objective of this study was to investigate the possibility of minimizing nitrogen fertilizer loss through slow-release nitrogen fertilizers with improving efficiency in their mineral and organic forms. As well as improving soil properties, in order to achieve productivity and high quality of wheat in Dakahlia governorate as example of the Middle Nile Delta region, preserve the environment and human health, and achieve sustainable agricultural development.

2. MATERIALS AND METHODS

2.1 The Experimental Site

The study was established at the experimental farm of Tag El-Ezz, Agricultural Research Station, Agricultural Research Center (ARC), Dakahlia governorate, Egypt (located at 30º 59\ N latitude, 31º58\ E longitude´). This area of Middle Nil Delta has a moderate climate with warm temperature, partly rainy winters and temperatures ranging from 14 to 28 ºC on average [21]. Main Soil properties of the experimental location were presented in Table 1 according to Page et al. [24] and Klute [25].

2.2 Nitrogen Fertilizer Types

Five nitrogen fertilizer types were evaluated. Three types of mineral N fertilizers i.e. urea (U), urea formaldehyde (UF) and sulfur coated urea (SCU) were used in this study, they are different in N concentration, coating materials, coating percentage and dissolution rate. In addition to, two organic N fertilizer types (compost (C) and vermicompost (VC)) were used. Urea, compost and vermicompost were procured from the Egyptian commercial market, while UF and SCU were produced from Delta Fertilizers and Chemical Industries Company- Talkha- Dakahlia governorate, Egypt. According to Salman, [26] and Vashishtha *et al*. [27] samples from nitrogen fertilizers that used in these experiments were analyzed and showed in Table 2.

2.3 Experiment Description

The experiments were carried out in a randomized complete block design (RCBD) with three replicates. The experiment included eleven nitrogen fertilization treatments as showed in Table 3.

Table 1. Average values of physical and chemical properties of the experimental site soil surface sample

Particle size distribution (%)				Textural Class	EC*, (dSm^{-1})	pH**	Organic matter (%)
C. sand	F. sand	Silt	Clay	Clayey			
4.04	15.45	38.13	42.38		3.87	7.94	1.16

Soluble ions (mmol L^{-1})								Available elements, mg Kg^{-1}		
Soluble cations				Soluble anions						
K^{+}	Na^{+}	Mg^{++}	Ca^{++}	HCO_3^{-}	CO_3^{--}	SO_4^{--}	Cl^{-}	N	P	K
4.12	21.68	6.22	6.68	1.85	0.00	17.60	19.22	38.90	8.70	241.40

** Soil Electrical Conductivity (EC) and soluble ions were determined in saturated soil paste extract. ** Soil pH was determined in soil suspension (1: 2.5)*

Table 2. Properties of nitrogen fertilizer types applied during the winter 2022/2023 and 2023/2024 seasons

Properties	Organic N fertilizer sources		Mineral N fertilizer sources		
	Vermicompost (VC)	Compost (C)	Urea (U)	Urea formaldehyde (UF)	Sulfur coated urea (SCU)
pH, 1:10	7.52	6.37	—	—	—
EC (1:10), dSm^{-1}	2.70	3.74	—	—	—
O.M%	33.60	33.04	—	—	—
Organic carbon%	35.60	18.00	—	—	—
Total N%	2.40	1.34	46.5	38.50	40.22
C/N ratio	14.83	13.43	—	—	—
Coating material	—	—	—	Formaldehyde	Sulfur
Color	Dark grey-Black	Dark brown	White	White	Yellow
Coating percentage	—	—	—	9.90	10.40
Dissolution rate minute.gm^{-1}	—	—	0.119	0.227	0.253

Table 3. Applied nitrogen fertilizer treatments and the equivalent in ton of fertilizer per hectare

Nitrogen fertilizer treatments	Equivalent to ton fertilizer.ha-1
N1 = 100% of NRD (nitrogen recommended dose) as usual urea (U), (control treatment)	0.384 ton U ha-1.
N2= 75% of NRD as urea formaldehyde (UF)	0.348ton UF ha-1.
N3= 75% of NRD as sulfur coated urea (SCU)	0.333 ton SCU ha-1.
N4= 75% of NRD as compost (C)	9.990 ton C ha-1.
N5= 75% of NRD as vermicompost (VC)	5.578 ton VC ha-1.
N6= 100% of NRD as compost (C)	13.321 ton C ha-1.
N7= 100% of NRD as vermicompost (VC)	7.438 ton VC ha-1.
N8= 50% of NRD as UF +25% of NRD as C	0.232 ton UF+ 3.330 ton C ha-1.
N9= 50% of NRD as UF +25% of NRD as VC	0.232 ton UF+ 1.860 ton VC ha-1.
N10= 50% of NRD as SCU +25% of NRD as C	0.222 ton SCU+ 3.330 ton C ha-1.
N11= 50% of NRD as SCU +25% of NRD as VC	0.222 ton SCU+ 1.860 ton VC ha-1.

In accordance with prior research findings, which advocated using 75% of slow- release nitrogen fertilizers were more economic rather than 100% from same fertilizers and more effective than usual urea at 100% NRD [8]. So, the additions of 100% urea formaldehyde and sulfur coated urea were omitted.

Wheat plants received N fertilizers at varying rates: 100% (178.5 kg N ha^{-1}), and 75% (133.9 kg N ha^{-1}) of the recommended dose either individually or in combination by organic N fertilizers. These fertilizers were urea formaldehyde (UF, 38.50% N), sulfur coated urea (SCU, 40.22% N), compost (C, 1.34% N) and vermicompost (VC, 2.40% N) comparing with usual urea (U, 46.5%N). Mineral Slow-release Fertilizers (UF and SCU) were applied during land preparation; however, urea fertilizer was divided into 3 equal doses added at 0, 25, and 45 days from sowing. Organic slow-release fertilizers (compost (C) and vermicompost (VC) were thoroughly mixed with (0-30 cm) soil surface two weeks before sowing.

Potassium was applied as potassium sulphate (48% K_2O) at the rate of 57.12 kg K_2O ha^{-1}. Calcium super phosphate (15.5% P_2O_5) was added to all experimental plots as a single dose before planting during land preparation at the rate of 53.55 kg P_2O_5 ha^{-1}. Wheat grains (*Triticum aestavium* L.) cv. (Giza 171) was purchased from Field Crops Research Institutes, ARC, Egypt. Planting done at 10th November during the two growing seasons of 2022/2023 and 2023/2024 with 166.6 kg ha^{-1} seeding rate.

2.4 Recorded Data

a. Vegetative growth parameters

Plants samples were obtained from each plot at the maximum vegetative growth stage (70 days after planting) to study various growth parameters as plant fresh weight (g), plant dry weight (g), plant height (cm) and leaf area (cm^2). Chlorophyll a and chlorophyll b (mg g^{-1} fresh weight of leaf) were determined according to Nayek *et al.* [28].

b. Yield, yield components and nutrients uptake

At harvest stage, yield characteristics and grain production (ton ha^{-1}) from each plot were listed. The harvested grains were processed to estimate the total amounts of N, P, and K concentration. The calculation of nutrients uptake was done using the following formula:

$$\text{Nutrients uptake in mature grains kg ha}^{-1} = \frac{\text{Nutrient concentration\% x grain yield kg ha}^{-1}}{100}$$

Protein percentage was estimated by multiplying nitrogen percentage by the factor (5.75) according to A.O.A.C. [29].

c. Soil analyses after harvest

According to Kenney and Nelson, [30] the soil available N (mg kg^{-1}) was determined in the soil samples (0-30 cm) from each experimental plot which were taken from soil surface, air-dried, ground, and passed through a 2 mm sieve, and by particle size distribution were prepared for the determination of available N using K_2SO_4 solution at different vegetative growth stages i.e. tillering, elongation, booting, filling and maturity of wheat crop. From each plot at harvesting time soil sample was collected and analyzed to determine EC (dSm^{-1}), pH and organic matter (%) as mentioned by Page *et al.* [24] and Klute [25].

2.5 Economic Analyses

The total cultivation costs and the gross return were calculated using the going rates for different items and methods on the market. To calculate net returns from each treatment, the entire cost of cultivation per hectare was reduced from the gross return.

Net return (LE. ha^{-1}) = Gross return ((LE. ha^{-1}) - Cost of cultivation (LE. ha^{-1})

Benefit cost ratio (BCR) was calculated treatment wise as below.

$$\text{Benefit Cost Ratio (BCR)} = \frac{\text{Gross return}}{\text{Cost of cultivation}}$$

2.6 Statistical Analyses

Results from identical tests conducted over two years were analyzed. The LSD test and Duncan's Multiple Comparisons Test [31] were used to evaluate significant differences across treatment means ($P < 0.05$). The present study's data were statistically analyzed using Co-STATE Computer Software, as described by Gomez and Gomez [32].

3. RESULTS AND DISCUSSION

3.1 Plant Measurements of Vegetative Growth Period

Data presented in Table 4 demonstrated the influence of nitrogen fertilizer from various types and rates on some vegetative growth characteristics of wheat plants under alluvial soil conditions in two seasons, namely plant height (cm), fresh weight (g $plant^{-1}$), dry weight (g $plant^{-1}$), leaf area (cm^2) and chlorophyll a & b content (mg g^{-1} FW).

The results demonstrated that various nitrogen types and rates had a positively significant substantial impact on the chlorophyll content and all other examined vegetative growth parameters. Combination treatment of urea formaldehyde and vermicompost (treatment N9) [50% of NRD as UF+ 25% of NRD as VC] was the superior where it recorded the highest values of all parameters at maximum vegetative growth stage with approximately increments 3.84% and 2.84% for plant height, 5.73% and 5.24% for fresh weight, 23.19% and 17.65% for dry weight, 12.26% and 8.25% for leaf area, 4.96% and 4.47% for chlorophyll a and 3.21% and 3.88% for chlorophyll b comparing with usual urea in two seasons, respectively.

These results may be attributed to the increment of nitrogen nutrient concentration in the root zone for plant absorption which reflects on plant growth and chlorophyll biosynthesis [33]. Urea formaldehyde fertilizer (UF) is more effective and efficient than usual urea (U) and sulfur coated urea (SCU). Applying usual urea (U) fertilizer results in a 30% loss because it dissolves quickly in the soil water, creating ammonia (NH^{+4}) and bicarbonate (HCO^{-3}), which are then lost by leaching, volatilization, and decomposition [34]. Urea formaldehyde (UF) as a mineral slow-release nitrogen fertilizer needs a time for dissolving more than usual urea (U) as shown in Table 2, reduces nitrogen losses and supplies plant with nitrogen nutrient for a long time [12]. Also, it works better in warmer climates (like the one in the Dakahlia Governorate) than cold. Furthermore, UF enhances the physical characteristics of the soil, particularly soil aggregation and permeability, which boosts roots' penetration into the soil and, as a result, increases plant uptake of nutrients. This phenomenon may be linked to microbial hydrolysis into ammonium, carbon dioxide, and water, which involves plant uptake and utilization. This result is in agreement with that listed by Awad *et al*. [11].

For vermicompost as an organic slow-release N fertilizer, considers more effective than compost where it is rich with organic matter and N nutrient in forms easier than compost and also has humic acids and adequate nutrients for maximum growth [19]. These results support the idea that the combination of mineral and organic fertilizer achieves the best growth and improves physiological activities and chlorophyll formation.

3.2 Yield and Yield Components at Harvest Stage

Data presented in Tables 5 & 6 show a significant impact of different nitrogen treatment applications on yield and yield component of wheat plants under alluvial soil of Dakahlia Governorate. All treatments of nitrogen fertilizer including different types and rates as presented positively and significantly effects on wheat grain yield, yield parameters [plant height (cm), plant weight (g), spike length (cm), spike weight (g), 1000 grain weight (g) and yield (ton ha^{-1})] and macronutrients uptake (N, P, K uptake and protein content) in the two successive growing seasons.

Application of sulfur coated urea (SCU 50% NRD) in combination with vermicompost (VC

25% NRD) (treatment N11) was the superior treatment application. Treatment N11 achieved the highest values of yield parameters. Also, it increased 1000 grain weight and grain yield in both growing seasons with relative increase 14.51% & 18.00% and 11.63% & 11.45%, respectively comparing with the control.

Regarding to macronutrients uptake (N, P and K uptake) and protein content, application of treatment N11 recorded the highest values of nutrients uptake and protein content. N uptake values increased by 24.83% and 17.93%, P uptake values increased by 22.88% and 27.31%, K uptake values increased by 28.31% and 27.19% and protein content increased by 16.32% and 15.64% in two successive seasons comparing with the control urea treatment, respectively.

This may be due to their capacity to control the release of nitrogen in respect to wheat plant requirements, making them more effective and efficient for plants than usual urea. They can also minimize nitrogen losses through leaching and feed roots with the necessary nutrients on a continuous basis [35].

The highest values were recorded by the combination treatment of sulfur coated urea and vermicompost with 75% application rate from recommended nitrogen dose (N11). Sulfur-coated urea (SCU) needs a long time to release more than usual urea (U) and urea formaldehyde (UF) as shown in Table 2, that makes its action appear lately in harvest stage. Additionally, SCU serves as a supply for the two essential main macronutrients (N and S) for plant development and yield production as well as it increases nitrogen fertilizer efficiency [13]. Moreover, SCU enhances plant nutrient uptake via sulfur oxidation in the soil, which lowers pH, improves soil-water relations, and increases nutrient availability [36].

Applying organic nitrogen fertilizers, such as compost (C) and vermicompost (VC), enhanced wheat grains' uptake of N, P, and K throughout the two seasons under investigation. These increases could be explained by the organic fertilizer's gradual release of nutrients in their accessible forms [37]. But, vermicompost has a higher nutrient content, a finer structure, breaks down and releases nutrients more quickly compared to compost and in ways that plants can absorb [38]. Nitrogen is released from compost in the form of ammonium ions, but vermicompost releases the same mineral in the form of nitrate, which is more easily absorbed by plants. Additionally, as organic matter decomposes, the organic acids generated by vermicompost dissolve fixed phosphorus from Fe and Al complexes in the soil [22,39].

Combination treatment of SCU and VC fertilizers has a positive effect on wheat plant yield and yield component in Dakahlia Governorate, which has a mild climate. These benefits may be explained by the ability of nutrients to meet plant requirements from a variety of sources over longer periods of time. Also, they increase the nutrients' availability in the soil for plant uptake and improve nutritional status of the plants, which benefits both yield and quality. These results are in harmony with that investigated by Yang *et al*. [23] and Saini et al. [40].

3.3 Soil Analyses

a- Impact of varying nitrogen fertilizer types and rates on the soil mineral nitrogen (mg kg^{-1}) during consecutive wheat growth stages.

During the two wheat growing seasons that followed, soil samples were taken in order to track the amount of accessible soil N. Table (7) show the amount of accessible nitrogen in the soil at various phases of vegetative growth as well as the remaining nitrogen after harvest (tillering, elongation, booting, filling and maturity). Tabulated data demonstrated that all slow-release nitrogen fertilizer treatments had a significant impact on the soil's nitrogen content at various interval phases. Nonetheless, the way the treatments were arranged differed depending on growth stage. Usual urea (N1) produced the highest value of accessible N content in the soil (68.52 - 70.36 mg kg^{-1}) in the tillering stage (30 days after planting), while a combination treatment of N11 produced the highest value in the elongation stage (60 days after planting). The same trend of data was demonstrated for this treatment was continued until the filling stage. Gradual increases in nitrogen content appeared when applying 50% of NRD as SCU +25% of NRD as C (N10) treatment from the tillering to maturity stages. The highest mineral nitrogen concentration in the soil achieved by N10 in maturity stage (74.62 and 76.66 mg kg^{-1}) during the two growing seasons, respectively.

Nitrogen has a big impact on how well ecosystems work [41]. Compared to other treatments, usual urea was more easily absorbed by plants and was therefore more effective in the tillering phase. Once urea is added to the soil, it undergoes a variety of physical, chemical, and biological reactions that result in NH^{+4}, which is then oxidized to NO^{-3} and removed through leaching or de nitrification. As a result, urea is therefore unable to provide the plant with all of the nitrogen it requires for the remainder of the growing stages until harvest [10,42].

Conversely, the amount of N released from mineral slow-release N fertilizers, such as UF and SCU, varies from 3 to 12 months, contingent upon several factors such as soil temperature, moisture content, coating thickness, number of microcracks in coating surface, and fertilizer particle size [43].

Urea formaldehyde (UF) fertilizer is most commonly utilized in warmer areas (such as the Dakahlia governorate), where it works better at higher temperatures than lower ones [12]. We found that UF has a higher rate of solubility than SCU, which facilitates and increases the amount of the fertilizer that the plant needs throughout its vegetative growth stages, resulting in less UF remaining in the soil than SCU. These results are in accordance with that recorded by Abd et al. [8], Awad et al. [11].

Regarding to organic fertilizers, the majority of the nitrogen is present in its organic form, which is generally not easily absorbed by plants [44]. In the process of nitrogen mineralization (i.e., the transformation of organic nitrogen into ammonium nitrogen), soil microorganisms play a mediating function. Numerous factors, including temperature, water content, soil properties, and organic material properties, might have an impact on N mineralization [19]. Since N is typically complex in organic chemical structures, organic additions may act as a slow-release fertilizer, with the rate and degree of mineralization having a significant impact on the amount of nutrient released [41].

Vermi compost (VC) gives plants access of macro and micronutrients by converting unavailable nutrients into forms that are easily absorbed by them, also, it ensures an adequate supply of nitrogen, improves the properties of the soil and encourages the build-up of carbon [45].

b- Impact of varying nitrogen fertilizer types and rates on some soil's chemical properties after harvesting.

Data in Figs. 1 to 3 showed a direct influence of different nitrogen types and rates on studied soil chemical properties after harvesting. It's clear that, different nitrogen fertilizer types at different rates positively affected soil's pH compared to initial soil (pH=7.94). All treatments decreased pH comparing with urea and the lowest pH value was achieved by treatment N11 (SCU 50% NRD + V C 25% NRD). Regarding to the soil's Ec after harvesting, treatment N11 too was the highest and reached value (4.55- 4.60 dSm^{-1}) in the soil as a negative impact comparing with the initial soil (3.87 dsm^{-1}), in both growing seasons. While, the treatment 100% of NRD as Vermicompost (VC) (N7) recorded the highest value of organic matter content (3.50- 3.52% in both growing seasons, respectively) in the soil after harvesting with the positive impact.

Mineral and organic slow-release nitrogen fertilizers at varying rates, either alone or in combination, have a positive impact on several soil chemical properties as pH, Ec, and organic matter. The N11 treatment was better, and this outcome might be related to beneficial effects of SCU and VC on soil fertility. Sulfur-coated urea lowers soil pH somewhat as a result of the sulfur coating, which also serves as a sulfur source for plants with minimal impact on soil's EC and organic matter [13].

Applying vermicompost lowers soil pH because it breaks down organic matter into organic acids like phosphoric and humic acids, which come from earthworm breakdown and lower the concentration of hydrogen ions (H^+). This moves the soil closer to neutrality [46]. Increases in Ec values following the application of vermicompost may be related to the amount of mineral ions released when organic wastes hydrolyze. Furthermore, the increase in the concentration of organic matter in the soil might be linked to the process of mineralization, which is facilitated by earthworm bacteria [47].

3.4 Economics

Economics of wheat crop production as affected by different nitrogen fertilizer types and rates had been shown in Table 8. The highest total cost of cultivation (L.E. ha^{-1}) was noticed with all treatments of vermicompost individually or in combination with mineral N source. The cultivation cost of control (usual urea) was 39648.4 and 61713.4 L.E. ha^{-1} in both growing seasons of 2022/2023 and 2023/2024. Whereas the highest cost of cultivation 57577.0 and 93534.0 L.E. ha^{-1} recorded by treatment N7 (100% of NRD as (VC)) followed by treatment N5 (75% of NRD as (VC)); with 52579.0 and 85204.0

L.E. ha^{-1} comparing with usual urea in two growing seasons, respectively. The maximum gross return of wheat crop was recorded by treatment N11 (50% of NRD as SCU +25% of NRD as VC) with 50017.6 and 90963.3 L.E. ha^{-1} followed by treatment N10 (50% of NRD as SCU +25% of NRD as C) with 48950.4 and 89033.8 L.E. ha^{-1} in two growing seasons, respectively. The highest net return of 7807.4 and 24107.4 L.E. ha^{-1} were obtained by treatment N10 in the two respective seasons. While, N5 and N7 recorded losses in both growing seasons. Application treatment of N7 recorded the lowest net return with -10634.6 in the first season and -8232.1 L.E. ha^{-1} in the second season, respectively. The highest benefit cost ratio (BCR) (1.18 and 1.37 in both growing seasons) was achieved by treatment N10.

The cultivation cost of usual urea at 100% NRD (control) was the lowest in both seasons, indicating that alternative nitrogen fertilizer sources recorded higher cultivation costs, either at 100% NRD or less, than the control in both growing seasons. The highest cost was in the case of vermicompost treatments, whether at a concentration of 100% NRD or 75% NRD, and this is due to its high price comparing with other treatments.

For gross return, the combination of SCU with VC was the highest, followed by the combination of SCU and C. This may be attributed to the ability of SCU as a source of N and S, as well as organic N fertilizers, in enhancing soil fertility and increasing yield productivity, which reflected in gross return.

Treatment N10 achieved a higher net return than the other treatments because its cultivation cost was lower than the other treatments at the similar N rate (75% NRD). In addition to the fact that the price per kilo of SCU ranged between 15-20 L.E. in the two seasons, whereas the price of compost ranged between 500-800 L.E. ton^{-1}, and only a small portion of the total nitrogen from the compost added was used in this treatment, equal to 3.332 ton. ha^{-1}.

The two treatments of N 5 and N7 resulted in a loss return due to the high cost of vermicompost. Vermicompost prices were 3000 and 5000 L.E. per ton for the two consecutive growing seasons. As a result, the hectare in the N5 treatment (75% NRD as vermicompost) required around 5.47 ton vermicompost with a price of 16,419 and 27,350 L.E. for the two seasons, respectively, whereas hectare in the N7 treatment (100% NRD as vermicompost) required approximately 7.14 ton. The VC price per hectare was 21,420 and 35,700 L.E. for both growing seasons. It is obvious that organic agriculture is quite expensive; hence it is sold in the marketplaces at outrageous prices corresponding with its cost. If organic fertilizers (VC and C) are priced at the same level as usual mineral agriculture, it will suffer significant losses and fail to generate the needed financial return.

Economically, it's clear that SCU at 50% NRD in combination with C at 25% NRD applied treatment listed the highest BCR and both could be a good alternative to usual urea for improving yield and farmer's income.

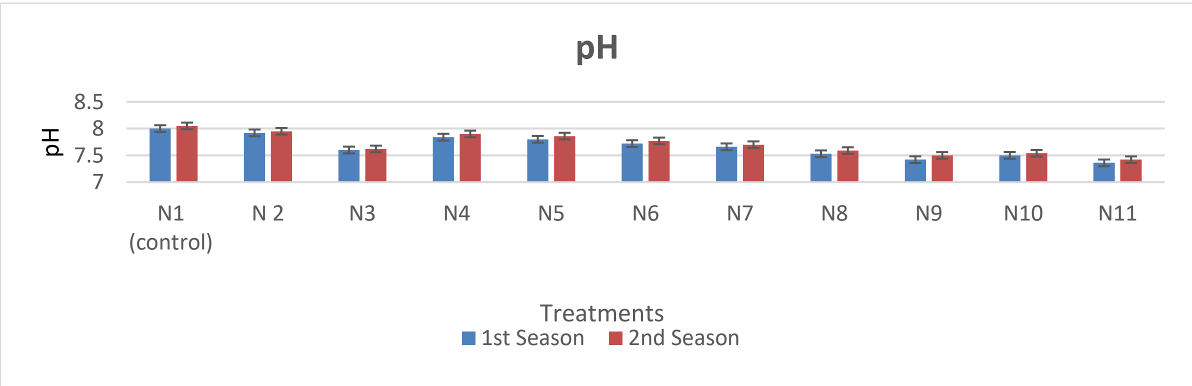

Fig. 1. Impact of varying nitrogen fertilizer types and rates on soil pH after harvesting during growing seasons of 2022/2023 and 2023/2024

__N1:__ 100% of NRD (nitrogen recommended dose) as usual urea (control); __N2:__ 75% of NRD as Urea formaldehyde (UF); __N3:__ 75% of NRD as Sulfur coated urea (SCU); __N4:__ 75% of NRD as Compost (C); __N5:__ 75% of NRD as Vermicompost (VC); __N6:__ 100% of NRD as Compost (C); __N7:__ 100% of NRD as Vermicompost (VC); __N8:__ 50% of NRD as UF +25% of NRD as C; __N9:__ 50% of NRD as UF +25% of NRD as VC ; __N10:__ 50% of NRD as SCU +25% of NRD as C; __N11:__ 50% of NRD as SCU +25% of NRD as VC

Table 4. Impact of various nitrogen fertilizer types and rates on some plant growth parameters during vegetative growth period of wheat plants under alluvial soil conditions in growing seasons 2022/2023 and 2023/2024

Treatments	Plant height Cm		Fresh weight g. plant $^{-1}$		Dry weight g. plant $^{-1}$		Leaf area cm^2		Chlorophyll a mg. g^{-1} FW		Chlorophyll b mg. g^{-1} FW	
	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season
N1 (control)	92.26^{ab}	93.50^{ab}	38.40^{ab}	38.92^{ab}	10.61^{c}	11.22^{c}	48.53^{c}	51.42^{c}	0.766^{d}	0.806^{d}	0.467^{b}	0.489^{b}
N 2	88.33^{b}	90.00^{b}	36.40^{ab}	37.66^{ab}	9.98^{d}	10.16^{d}	47.59^{c}	50.37^{c}	0.775^{c}	0.815^{c}	0.459^{bc}	0.480^{bc}
N3	82.06^{c}	84.22^{c}	35.80^{ab}	37.25^{ab}	9.89^{e}	10.04^{e}	45.52^{d}	47.16^{d}	0.742^{e}	0.790^{e}	0.453^{c}	0.468^{c}
N4	65.00^{g}	66.10^{g}	24.66^{d}	28.66^{d}	8.54^{j}	8.62^{j}	29.46^{h}	30.16^{h}	$0. 680^{j}$	0.717^{j}	0.405^{g}	0.424^{g}
N5	67.60^{g}	69.48^{g}	27.50^{d}	28.50^{d}	8.62^{j}	8.80^{j}	35.05^{g}	38.22^{g}	0.694^{i}	0.728^{i}	0.413^{fg}	0.437^{fg}
N6	68.53^{fg}	70.33^{fg}	25.13^{d}	27.66^{d}	8.94^{i}	9.12^{i}	36.24^{fg}	40.33^{fg}	0.703^{h}	0.736^{h}	0.420^{f}	0.443^{f}
N7	74.00^{ef}	76.30^{ef}	28.62^{cd}	32.42^{cd}	9.15^{h}	9.26^{h}	37.11^{f}	43.00^{f}	0.714^{g}	0.749^{g}	0.430^{e}	0.451^{e}
N8	80.40^{cd}	81.39^{cd}	33.80^{bc}	36.14^{bc}	9.64^{f}	9.92^{f}	40.21^{e}	44.36^{e}	0.740^{e}	0.779^{f}	0.444^{d}	0.475^{d}
N9	95.80^{a}	96.16^{a}	40.60^{a}	40.96^{a}	13.07^{a}	13.20^{a}	54.48^{a}	55.66^{a}	0.804^{a}	0.842^{a}	0.482^{a}	0.508^{a}
N10	75.60^{de}	78.92^{de}	29.00^{cd}	30.12^{cd}	9.27^{g}	9.36^{g}	37.86^{f}	40.52^{f}	0.728^{f}	0.765^{f}	0.438^{de}	0.458^{de}
N11	93.00^{ab}	93.91^{ab}	39.25^{a}	40.00^{a}	12.37^{b}	12.68^{b}	52.26^{b}	53.72^{b}	0.790^{b}	0.829^{b}	0.476^{a}	0.499^{a}
LSD at 0.05	5.68	3.18	5.33	3.43	0.083	0.088	1.77	3.55	0.007	0.006	0.008	0.009

Means within a row followed by a different letter (s) are statistically different at $p < 0.05$

N1: *100% of NRD (nitrogen recommended dose) as usual urea (control);* ***N2:*** *75% of NRD as Urea formaldehyde (UF);* ***N3:*** *75% of NRD as Sulfur coated urea (SCU);* ***N4:*** *75% of NRD as Compost (C);* ***N5:*** *75% of NRD as Vermicompost (VC);* ***N6:*** *100% of NRD as Compost (C);* ***N7:*** *100% of NRD as Vermicompost (VC);* ***N8:*** *50% of NRD as UF +25% of NRD as C;* ***N9:*** *50% of NRD as UF +25% of NRD as VC ;* ***N10:*** *50% of NRD as SCU +25% of NRD as C;* ***N11:*** *50% of NRD as SCU +25% of NRD as VC*

Table 5. Impact of various nitrogen fertilizer types and rates on yield and yield components of wheat plants under alluvial soil conditions in growing seasons of 2022/2023 and 2023/2024

Treatments	Plant height cm		Plant weight g		Spike length cm		Spike weight g		1000 grain weight g		Grain yield ton ha^{-1}	
	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season
N1(control)	92.66^{c-f}	97.06^{c-f}	20.00c	21.42c	16.42^{i}	18.14^{i}	2.72i	2.98i	61.13def	62.42^{def}	7.595i	7.652i
N 2	90.66^{def}	97.72^{def}	21.00c	21.69c	17.66^{h}	19.16^{h}	2.84h	3.00h	61.42def	63.00def	7.683h	7.723h
N 3	95.33^{b-f}	97.42^{b-f}	21.42c	22.33c	18.33^{g}	20.36^{g}	3.00g	3.32g	62.55c-f	63.22c-f	7.783g	7.818g
N4	87.00^{f}	89.66^{f}	12.00d	15.16d	17.66^{h}	18.52^{h}	2.66i	2.80i	60.50ef	61.40ef	7.333k	7.378k
N5	88.66^{ef}	91.66^{ef}	14.00d	16.08d	15.66^{j}	17.96^{j}	2.45j	2.50j	59.60f	60.66f	7.514j	7.557j
N6	96.66 $^{b-e}$	100.41^{b-e}	22.33c	22.82c	18.66^{f}	21.28^{f}	3.12f	3.40f	63.60cde	65.20cde	7.866f	7.911f
N7	97.66^{bcd}	101.12^{bcd}	22.66c	23.18c	19.07^{e}	21.62^{e}	3.36e	3.52e	64.66cd	67.33cd	7.956e	7.997e
N8	100.42^{abc}	102.13^{abc}	23.33c	25.66c	19.66^{d}	23.14^{d}	3.45d	3.66d	65.00bc	65.22bc	8.042d	8.092d
N9	102.00^{ab}	104.66^{ab}	31.66b	36.85b	20.00^{c}	23.96^{c}	3.84c	3.90c	65.80bc	66.35bc	8.123c	8.175c
N10	102.66^{ab}	105.00^{ab}	39.33a	40.35a	20.33^{b}	24.66^{b}	4.00b	4.06b	68.22ab	68.33ab	8.297b	8.347b
N11	106.33^{a}	110.42^{a}	40.00a	42.16a	20.66^{a}	25.14^{a}	4.10a	4.15a	70.00a	73.66a	8.478a	8.528a
LSD at 0.05	8.51	7.87	5.13	8.36	0.083	0.330	0.085	0.085	3.55	3.18	0.040	0.080

Means within a row followed by a different letter (s) are statistically different at $p < 0.05$

***N1:** 100% of NRD (nitrogen recommended dose) as usual urea (control); **N2:** 75% of NRD as Urea formaldehyde (UF); **N3:** 75% of NRD as Sulfur coated urea (SCU); **N4**: 75% of NRD as Compost (C); **N5:** 75% of NRD as Vermicompost (VC); **N6**: 100% of NRD as Compost (C); **N7:** 100% of NRD as Vermicompost (VC); **N8**: 50% of NRD as UF +25% of NRD as C; **N9**: 50% of NRD as UF +25% of NRD as VC ; **N10**: 50% of NRD as SCU +25% of NRD as C; **N11**: 50% of NRD as SCU +25% of NRD as VC*

Table 6. Impact of various nitrogen fertilizer types and rates on N, P and K uptake and protein content of wheat plants under alluvial soil conditions in growing seasons of 2022/2023 and 2023/2024

Treatments	N		P		K		Protein %	
	Uptake (kg ha^{-1})							
	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season
N1 (control)	17769^{g}	198.16^{g}	20.28^{abc}	20.56^{abc}	161.74^{ef}	172.15^{ef}	12.93^{g}	13.62^{g}
N 2	192.83^{e}	201.59^{e}	20.90^{abc}	21.85^{abc}	168.24^{e}	177.64^{e}	13.22^{f}	13.91^{f}
N 3	193.00^{e}	192.33^{e}	20.06^{abc}	21.66^{abc}	155.65^{fg}	161.84^{fg}	13.45^{e}	14.14^{e}
N4	151.77^{i}	161.55^{i}	15.54^{c}	16.21^{c}	127.59^{i}	134.28^{i}	11.90^{i}	12.59^{i}
N5	157.03^{h}	167.72^{h}	16.30^{c}	17.30^{c}	131.47^{i}	139.08^{i}	12.01^{h}	12.76^{h}
N6	176.98^{g}	187.50^{g}	19.11^{bc}	19.54^{bc}	147.08^{h}	155.84^{h}	14.26^{d}	14.89^{d}
N7	183.00^{f}	193.52^{f}	19.23^{bc}	20.13^{bc}	152.75^{gh}	159.91^{gh}	14.43^{c}	15.00^{d}
N8	202.66^{d}	215.22^{d}	22.18^{ab}	23.21^{ab}	178.52^{d}	184.47^{d}	14.49^{c}	15.29^{c}
N9	209.68^{c}	219.89^{c}	23.32^{ab}	24.51^{ab}	192.61^{c}	200.28^{c}	14.83^{b}	15.46^{b}
N10	214.87^{b}	227.03^{b}	24.20^{ab}	25.37^{ab}	199.94^{b}	211.18^{b}	14.89^{b}	15.64^{b}
N11	221.82^{a}	233.62^{a}	24.92^{a}	26.18^{a}	207.70^{a}	219.15^{a}	15.04^{a}	15.75^{a}
LSD at 0.05	2.68	6.34	6.15	6.73	6.78	7.36	0.181	0.480

Means within a row followed by a different letter (s) are statistically different at $p < 0.05$

***N1:** 100% of NRD (nitrogen recommended dose) as usual urea (control); **N2:** 75% of NRD as Urea formaldehyde (UF); **N3:** 75% of NRD as Sulfur coated urea (SCU); **N4**: 75% of NRD as Compost (C); **N5:** 75% of NRD as Vermicompost (VC); **N6**: 100% of NRD as Compost (C); **N7:** 100% of NRD as Vermicompost (VC); **N8**: 50% of NRD as UF +25% of NRD as C; **N9**: 50% of NRD as UF +25% of NRD as VC ; **N10**: 50% of NRD as SCU +25% of NRD as C; **N11**: 50% of NRD as SCU +25% of NRD as VC*

Table 7. Impact of various nitrogen fertilizer types and rates on available soil N at different growth stages (days after planting (DAP)) during growing seasons 2022/2023 and 2023/2024

Treatments	Soil available N (mg kg^{-1})									
	Tillering stage (30 DAP)		Elongation stage (60 DAP)		Booting stage (90 DAP)		Filling stage (120 DAP)		Maturity stage (150 DAP)	
	1^{st} Season	2^{nd} Season	1^{st} Season	2^{nd} Season	1^{st} Season	2^{nd} Season	1^{st} Season	2^{nd} Season	1^{st} Season	2^{nd} Season
N1 (control)	68.52^{a}	70.36^{a}	71.00^{b}	72.52^{b}	70.86^{d}	71.66^{e}	70.00^{h}	70.56^{h}	60.00^{k}	62.13^{k}
N 2	67.66^{d}	69.40^{d}	69.66^{c}	71.42^{c}	71.25^{c}	72.26^{cd}	70.75^{f}	71.85^{f}	70.66^{j}	71.46^{j}
N 3	67.86^{c}	69.66^{c}	69.45^{d}	71.86^{d}	71.36^{bc}	72.54^{c}	73.13^{c}	74.20^{c}	70.85^{i}	71.62^{i}
N4	63.66^{j}	64.52^{j}	67.05^{j}	67.20^{j}	68.13^{i}	68.20^{i}	69.44^{j}	68.90^{j}	71.67^{g}	72.66^{g}
N5	64.82^{i}	65.66^{i}	67.40^{i}	67.82^{i}	68.52^{h}	68.66^{h}	69.65^{i}	70.56^{i}	71.40^{h}	72.12^{h}
N6	65.16^{h}	67.33^{h}	67.84^{h}	69.66^{h}	68.56^{h}	69.86^{h}	70.12^{h}	71.28^{h}	74.33^{b}	75.42^{b}
N7	66.42^{g}	68.36^{g}	68.33^{g}	70.18^{g}	68.90^{g}	71.00^{g}	70.30^{g}	71.76^{g}	73.65^{d}	74.80^{d}
N8	67.12^{f}	69.02^{f}	68.56^{f}	71.20^{f}	69.13^{f}	71.25^{f}	72.46^{e}	73.66^{e}	73.42^{e}	74.36^{e}
N9	68.00^{c}	70.00^{c}	71.35^{a}	73.00^{a}	71.45^{ab}	73.85^{b}	73.40^{b}	74.66^{b}	73.20^{f}	74.00^{f}
N10	67.35^{e}	69.26^{e}	69.13^{e}	71.40^{e}	69.33^{e}	71.40^{e}	72.84^{d}	73.80^{d}	74.62^{a}	76.66^{a}
N11	68.23^{b}	70.12^{b}	71.45^{a}	73.16^{a}	71.56^{a}	74.33^{a}	73.66^{a}	74.92^{a}	74.00^{c}	75.16^{c}
LSD at 0.05	0.172	0.159	0.180	0.172	0.159	0.160	0.171	0.977	0.178	0.159

Means within a row followed by a different letter (s) are statistically different at $p < 0.05$

***N1:** 100% of NRD (nitrogen recommended dose) as usual urea (control); **N2:** 75% of NRD as Urea formaldehyde (UF); **N3:** 75% of NRD as Sulfur coated urea (SCU); **N4**: 75% of NRD as Compost (C); **N5:** 75% of NRD as Vermicompost (VC); **N6**: 100% of NRD as Compost (C); **N7:** 100% of NRD as Vermicompost (VC); **N8**: 50% of NRD as UF +25% of NRD as C; **N9**: 50% of NRD as UF +25% of NRD as VC ; **N10**: 50% of NRD as SCU +25% of NRD as C; **N11**: 50% of NRD as SCU +25% of NRD as VC*

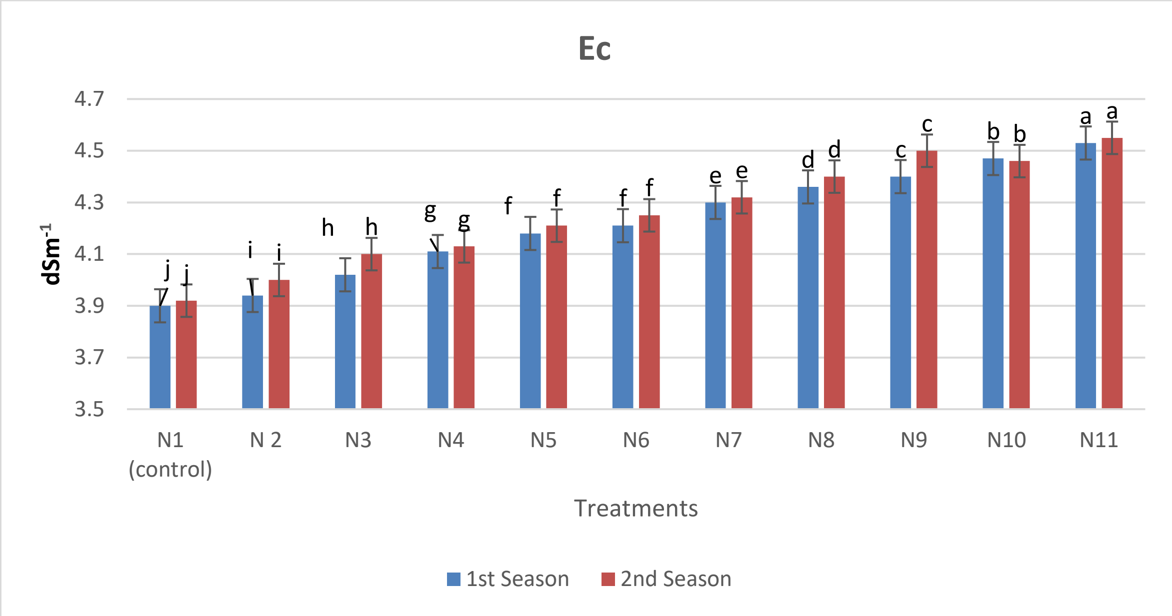

Fig. 2. Impact of varying nitrogen fertilizer types and rates on soil EC after harvesting during growing seasons of 2022/2023 and 2023/2024

***N1:** 100% of NRD (nitrogen recommended dose) as usual urea (control); **N2:** 75% of NRD as Urea formaldehyde (UF); **N3:** 75% of NRD as Sulfur coated urea (SCU); **N4:** 75% of NRD as Compost (C); **N5:** 75% of NRD as Vermicompost (VC); **N6:** 100% of NRD as Compost (C); **N7:** 100% of NRD as Vermicompost (VC); **N8:** 50% of NRD as UF +25% of NRD as C; **N9:** 50% of NRD as UF +25% of NRD as VC ; **N10:** 50% of NRD as SCU +25% of NRD as C; **N11:** 50% of NRD as SCU +25% of NRD as VC*

Table 8. Economic analyses for wheat crop due to response to different N treatments during growing seasons of 2022/2023 and 2023/2024

Treatments	(LE. ha^{-1})						BCR*	
	Total costs		Gross return		Net return			
	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season
N1(control)	39648.4	61713.4	44808.0	81620.7	5159.6	19907.3	1.13	1.32
N2	41369.2	64783.6	45917.3	83397.8	4548.2	18614.2	1.10	1.28
N3	41155.0	64498.0	45327.6	82382.3	4172.6	17884.3	1.10	1.27
N4	41155.0	65830.8	43263.4	78701.1	2108.4	12870.3	1.05	1.19
N5	52579.0	85204.0	44330.6	80605.2	-8248.4	-4598.8	0.84	0.94
N6	42702.0	68306.0	46408.8	84387.9	3706.9	16081.9	1.08	1.23
N7	57577.0	93534.0	46942.4	85301.9	-10634.6	-8232.1	0.81	0.91
N8	42440.2	65116.8	47447.9	86317.4	5007.8	21200.6	1.11	1.32
N9	44266.8	71745.1	47953.4	87205.9	3686.6	15460.8	1.08	1.21
N10	41143.1	64926.4	48950.4	89033.8	7807.4	24107.4	1.18	1.37
N 11	44124.0	71554.7	50017.6	90963.3	5893.6	19408.6	1.13	1.27

BCR: benefit cost ratio; **N1: 100% of NRD (nitrogen recommended dose) as usual urea (control); **N2:** 75% of NRD as Urea formaldehyde (UF); **N3:** 75% of NRD as Sulfur coated urea (SCU); **N4:** 75% of NRD as Compost (C); **N5:** 75% of NRD as Vermicompost (VC); **N6:** 100% of NRD as Compost (C); **N7:** 100% of NRD as Vermicompost (VC); **N8:** 50% of NRD as UF +25% of NRD as C; **N9:** 50% of NRD as UF +25% of NRD as VC ; **N10:** 50% of NRD as SCU +25% of NRD as C; **N11:** 50% of NRD as SCU +25% of NRD as VC*

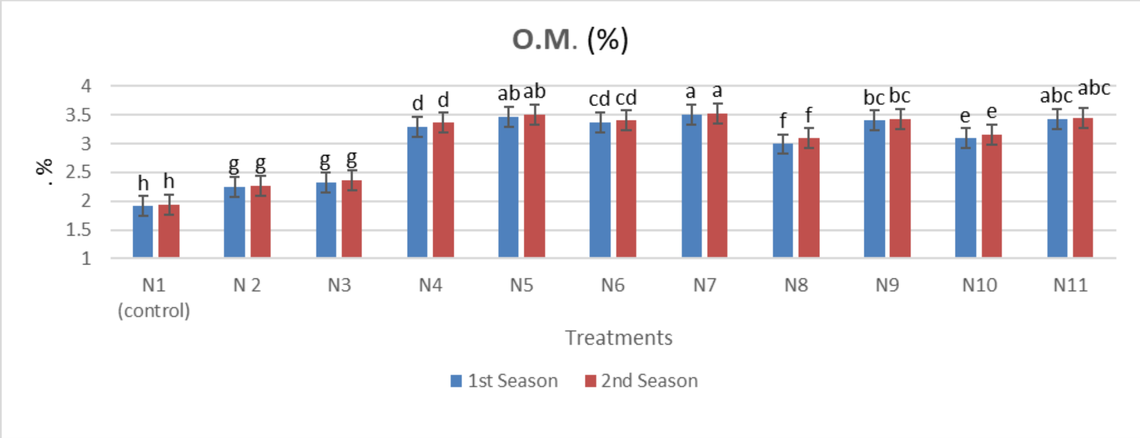

Fig. 3. Impact of varying nitrogen fertilizer types and rates on soil organic matter after harvesting during growing seasons of 2022/2023 and 2023/2024

***N1:** 100% of NRD (nitrogen recommended dose) as usual urea (control); **N2:** 75% of NRD as Urea formaldehyde (UF); **N3:** 75% of NRD as Sulfur coated urea (SCU); **N4:** 75% of NRD as Compost (C); **N5:** 75% of NRD as Vermicompost (VC); **N6:** 100% of NRD as Compost (C); **N7:** 100% of NRD as Vermicompost (VC); **N8:** 50% of NRD as UF +25% of NRD as C; **N9:** 50% of NRD as UF +25% of NRD as VC ; **N10:** 50% of NRD as SCU +25% of NRD as C; **N11:** 50% of NRD as SCU +25% of NRD as VC*

4. CONCLUSION

The acquired results demonstrated the ability to apply slow-release nitrogen fertilizers in mineral or organic form to sustain agricultural output and preserve environmental quality. The results of this study indicated that usual urea was not as effective or efficient as slow-release nitrogen fertilizers in terms of crop quality, productivity, soil qualities and reduction loss of nitrogen fertilizer. Therefore, slow- release nitrogen fertilizers are the best alternative to urea. From the study's findings, we can recommend adding treatment N10 (50% of NRD as SCU +25% of NRD as C) to wheat plants grown on alluvial soils as an effective choice because of its advantages over urea in terms of yield, quality, and cost.

This study is unique in that it examines slow-release fertilizers in combination with organic fertilizers with specific requirements, such as vermicompost versus compost. Also, compensating for the decline in mineral fertilization rates using environmentally friendly, high-use efficiency, and low-loss fertilizers, as well as trying to adapt to climate change and boost production. My wheat production and specifications are in accordance with food safety standards and agricultural quarantine regulations for export. Finally, we need to generate technologies to decrease the coast of producing organic vermicompost and other alternative's fertilizers, and to register mineral slow- release fertilizers in ministry of agriculture committee for fertilizers.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://prh.ikprress.org/review-history/12354