



Article

Improving Growth and Productivity of Potato Under Different Sources of Organic and Biofertilizers

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Abstract: Excessive use of mineral nitrogen fertilizers is a major factor leading to soil nutrient loss and environmental pollution, so reducing nitrogen use and finding sustainable alternatives are essential to improving potato productivity and resource efficiency. Two field experiments were conducted during the 2023 and 2024 seasons (early summer plantation) at Kaha Vegetable Research Farm, Qalyubia Governorate, Egypt, using a randomized complete block design with seven treatments. The study evaluated the effects of different mineral nitrogen levels (100%, 75%, and 50% from the recommended dose) with compensating for the deficiency with alternative organic sources (liquid biogas manure, compost tea, and the biofertilizer *Azospirillum brasilense*) on potato growth, yield, and soil properties. Results indicated that use of liquid biogas manure integration with mineral nitrogen fertilization at 75% of the recommended dose improved vegetative growth parameters, growth, yield and its components. In addition, it improved microbiological properties, enzyme activity and available macronutrient levels in soil in comparison to all treatments in both seasons. It can be concluded that the application of liquid organic fertilizers or biofertilizers are a promising method to reduce mineral nitrogen fertilizers, improve the growth parameters, productivity of potato and increase soil fertility.

Key words: Potato, liquid biogas manure, compost tea, *Azospirillum brasilense*, nitrogen fertilization.

1. Introduction

Potato plant (*Solanum tuberosum* L.) is a major strategic crop in Egypt due to their high nutritional value and export importance. Therefore, improving their productivity and quality is a top priority for agricultural decision makers. Effective fertilization programs must therefore be developed to achieve food security and increase economic returns (El-Ghamry *et al.*, 2025). Egypt is the largest producer of potatoes in Africa; the cultivated area expanded to 236 thousand hectares, while total production reached 6.90 million tons by 2023 (FAO, 2022 and FAOSTAT, 2025).

Crop productivity depends on several key factors, most notably soil quality and fertility (**Farias *et al.*, 2025**). The integrated fertilization system represents an advanced approach to agriculture that aims to maximize resource utilization. This system combines various types of fertilizers, such as biofertilizers, chemical fertilizers, nano fertilizers, and organic fertilizers, to enhance soil properties and effectively nourish crops. The benefits of this approach extend beyond increasing crop productivity to improving soil quality, supporting food and environmental security and combating climate change by significantly reducing greenhouse gas emissions compared to traditional methods (**El-Bialy *et al.*, 2025**).

Fertilization is essential for achieving high yields and superior quality in potato crops. Nitrogen, phosphorus, and potassium are among the most important nutrients required for agriculture, and precise fertilization improves the efficiency of their use. This is achieved by providing mineral nutrition specifically designed to meet the plant's needs at each stage of its growth, leading to improved productivity and environmental sustainability (**Ranjan and Sow, 2021**).

Nitrogen is a vital element for plant growth and development, but excessive use of mineral nitrogen fertilizers poses serious threats. These threats not only affect crop health but also human well-being, due to the potential health risks associated with nitrate accumulation in food. Therefore, these risks must be mitigated by ensuring that we do not over-rely on mineral nitrogen fertilizers (**Abd El-Hady *et al.*, 2024**).

Azospirillum brasilense is an important microorganism as a free living bacteria in agriculture. It belongs to the group of plant growth promoting bacteria (PGPR) and is characterized by its ability to fix atmospheric nitrogen. This bacterium plays a crucial role in providing nitrogen to plants, reducing reliance on chemical fertilizers and contributing to sustainable agricultural practices. *Azospirillum brasilense* lives in a symbiotic relationship with plant roots, providing the nitrogen necessary for their growth, while benefiting from the environment and nutrients provided by the plants. This mutual relationship improves soil health and increases agricultural production naturally and efficiently (**Galindo *et al.*, 2022; Zaheer *et al.*, 2022 and Shabana, *et al.*, 2024**).

Organic fertilization, such as liquid biogas manure and compost tea, represents a promising way to reduce reliance on mineral fertilizers. Liquid biogas manure, a byproduct of anaerobic digestion, improves plant health and growth while simultaneously enriching soil fertility (**Møller *et al.*, 2022**). Compost tea is an aqueous extract of compost, produced through a process of extracting nutrients and beneficial microorganisms; this extract is a liquid bio-amendment rich in micronutrients and aerobic microorganisms, making it an effective tool for improving plant health and enhancing soil fertility (**Hafez *et al.*, 2024**).

Therefore, this research aims to evaluate the potential of alternative fertilization methods for improving potato yield. It also focuses on reducing the use of chemical nitrogen fertilizers, which contributes to the development of sustainable agricultural systems and supports food security.

2. Materials and Methods

2.1. Location and soil properties

This field study was conducted over two consecutive growing seasons of 2023 and 2024 in Kaha Vegetable Research Farm, Qalyubia Governorate, Egypt (latitude 30°17'25.7"N 31°11'50.1"E). The primary objective of this experiment was to study the effect of using liquid organic fertilizers (liquid biogas manure and compost tea) and biofertilizers (*Azospirillum brasilense*) on rationalizing the use of mineral nitrogen fertilizers and improving the growth, productivity and quality of potatoes (*Solanum tuberosum* L.) under soil clay loam conditions. Before the sowing, initial soil samples were collected from a depth of 0-25 cm to evaluate their properties. Standard analytical methods were used for these samples, based on those described in **Sparks *et al.* (2020), Dane and Topp (2020), Allen (1959), Williams and Davis, (1965) and Martin (1950)**. Table (1) showed the physical, chemical and microbiological of the soil under study.

Table (1). Physical, chemical and biological properties of the experimental soil

Type of analysis	Unit	Seasons	
		2023	2024
Particle size distribution			
Clay	%	50.00	50.09
Silt	%	25.93	25.97
Fine sand	%	8.85	8.82
Coarse sand	%	15.22	15.12
Textural class		Clay loam	Clay loam
Chemical analysis			
pH (1:2.5) soil – water suspension		8.00	7.96
EC (saturation paste extract)	dS/m	1.76	1.78
Organic matter	%	1.47	1.49
Organic carbon	%	0.85	0.86
CaCO ₃	mg/kg	38.37	38.39
Soluble cations			
Ca ⁺⁺	mmol _c L ⁻¹	9.09	9.07
Mg ⁺⁺	mmol _c L ⁻¹	5.19	5.22
Na ⁺	mmol _c L ⁻¹	2.44	2.42
K ⁺	mmol _c L ⁻¹	0.93	1.09
Soluble anions			
CO ₃ ⁼	mmol _c L ⁻¹	-	-
HCO ₃ ⁻	mmol _c L ⁻¹	2.36	2.38
Cl ⁻	mmol _c L ⁻¹	9.32	9.35
SO ₄ ⁼	mmol _c L ⁻¹	5.97	6.07
Available Macronutrients			
N	mg/kg	52.21	52.27
P	mg/kg	3.94	3.96
K	mg/kg	61.43	62.47
Microbiological analysis			
Total bacterial count	cfu/g × 10 ⁵	22.00	25.00
Total actinomycetes	cfu/g × 10 ³	27.00	31.00
Total fungi	cfu/g × 10 ³	11.00	14.00

cfu/g: Colony forming unit/gram

2.2. Material

Potatoes (*Solanum tuberosum* L.) cultivar Spunta seed tubers were imported from abroad (Holland).

Compost used in this study was obtained from the Training Center for the Recycling of Agricultural Wastes (TCRAR) in Moshtohor, Qalyubia Governorate, Egypt. This compost served as used for preparing compost tea. The physical and chemical properties of the compost were characterized based on the methods of **APHA (1989)** and **Black (1965)**. Microbiological assays for total, fecal coliforms, *Salmonella* and *Shigella* were performed following **Difco (1985)**. Additionally, the presence of weed seeds and nematodes were assessed as described by **Yu et al. (2010)** and **Rice et al. (2017)**. Parasite was assays according to **Jirillo et al. (2014)**. Table (2) shows the physical, chemical and microbiological properties of compost.

Table (2). Physicochemical and biological characteristics of compost used in extracting compost tea

Composition	Units	Compost
Density	kg/m ³	590.00
Moisture content	%	26.00
pH (1:10)		7.59
EC (1:10)	dSm ⁻¹	3.65
N-NH ₄	mg kg ⁻¹	90.00
N-NO ₃	mg kg ⁻¹	405.00
Total nitrogen	%	1.86
Organic matter	%	57.21
Organic carbon	%	33.18
Ash	%	42.79
C/N ratio		17.84: 1
Total phosphorus	%	1.46
Total potassium	%	1.14
Weed seeds		Nil
Nematode	Larava/200g	Nil
Parasite	cyst/g	Nil
Total coliform	cfu/g	Not detected
Faecal coliform	cfu/g	Not detected
<i>Salmonella</i> and <i>Shigella</i>	cfu/g	Not detected

cfu/g: Colony forming unit/gram

Compost tea (CT) was formulated by steeping mature compost in tap water at a 1:10 (w/v) ratio within an open container. The mixture was continuously stirred and steeped at ambient temperature for one week to extract soluble organic matter and microorganisms. To promote microbial population, 0.5% (v/v) molasses was subsequently added to the solution. This preparation according to the method described by **Scheuerell and Mahaffee (2002)** and **Ingham (2005)**. Compost tea (CT) was applied to the soil at a rate of 75 l/fed. and this quantity was divided into three equal doses during the first, second and third irrigation stages. Physicochemical and biological characteristics of CT illustrated in Table (3).

Liquid biogas manure (LBM) was obtained from the Training Center for the Recycling of Agricultural Wastes (TCRAR) in Moshtohor, Qalyubia Governorate, Egypt. Liquid biogas manure (LBM) was applied to the soil at a rate of 75 l/fed. and this quantity was divided into three equal doses during the first, second and third irrigation stages. Physicochemical and biological characteristics of LBM illustrated in Table (3).

Azospirillum brasilense (BF) was obtained from Agricultural Microbiology Department, Soils, Water and Environment Research Institute (SWERI), ARC, Giza, Egypt. *Azospirillum brasilense* (BF) was applied to the soil at a rate 5 l/fed. during the first, second and third irrigation stages. The irrigation method during the study was surface irrigation.

Mineral fertilization was done at rate of 180, 75 and 96 unit of N, P₂O₅, K₂O, respectively per feddan. Ammonium nitrate (33.5% N) was applied at different rates 90, 135 and 180 unit of N/fed represented on 50, 75 and 100% from recommended dose in three equal doses, the first one applied in planting date and repeated every 3 weeks. Supper calcium phosphate (15.5% P₂O₅) was applied at rate 75 unit of P₂O₅ /fed, calcium nitrate (17% Ca and 15.5% N) at 50 kg /fed., magnesium sulphate (10% Mg) at 100 kg /fed. Were added once before planting during tillage of soil. Potassium sulphate (48% K₂O) was applied at rate 96 unit of K₂O/fed in three equal doses, starting from the first irrigation. It worth noting that N units in calcium nitrate represented 15.5 unit of N. This quantity was reduced from mineral N as recommended dose.

Table (3). Physicochemical and biological characteristics of compost tea and liquid biogas manure in a field experiment

Composition	Units	Compost tea	Liquid biogas manure
pH		7.02	7.63
EC	dSm ⁻¹	3.87	4.77
Organic matter	%	9.43	29.28
Organic carbon	%	5.47	16.98
Total nitrogen	mg kg ⁻¹	425.31	2465.00
N-NH ₄	mg kg ⁻¹	105.23	289.00
N-NO ₃	mg kg ⁻¹	163.09	20.00
Total phosphorus	mg kg ⁻¹	77.95	2588.00
Total potassium	mg kg ⁻¹	138.19	6095.00
Total counts of bacteria	cfu/ml	3.00 × 10 ⁷	21.00 × 10 ⁵
Total counts of actinomycetes	cfu/ml	5.00 × 10 ⁵	65.00 × 10 ⁴
Total counts of fungi	cfu/ml	11.00 × 10 ⁴	16.00 × 10 ⁴
Total coliform	cfu/ml	Not detected	Not detected
Faecal coliform	cfu/ml	Not detected	Not detected
<i>Salmonella</i> and <i>Shigella</i>	cfu/ml	Not detected	Not detected
Parasite	cyst/ml	Nil	Nil

2.3. Experimental treatments

The experiment included seven treatments with three replicates which were arranged in a randomized complete blocks design, seven treatments are laid out as following:

T1: 100% N (Control), T2: 75% N + *Azospirillum brasilense* (BF), T3: 75% N + Compost tea (CT), T4: 75% N + Liquid biogas manure (LBM), T5: 50% N + *Azospirillum brasilense* (BF), T6: 50% N + Compost tea (CT) and T7: 50% N + Liquid biogas manure (LBM).

Each experimental plot consisted of four ridges; each one was 4 m length and 0.75 m width with an area 12 m². Good quality potato (*Solanum tuberosum* L.) cv. Spunta seed tubers were used in both seasons. Tubers were planted at the bottom of the ridge at a distance of 30 cm apart on 2 and 3 January during both season 2023 and 2024, respectively (early summer plantation). All agricultural practices were performed as recommended by Ministry of Agriculture and Land Reclamation.

2.4. Sampling and Collecting Data

Total bacterial counts (Allen, 1959), actinomycetes (Williams and Davis, 1965), and fungal counts (Martin, 1950), nitrogenase activity (μmole C₂H₄/gm soil) (Somasegaran and Hoben, 1994), dehydrogenase activity (μg/g dry soil/day) (Skujins, 1976) and total phosphatase (mg/ PNP/g dry soil) (Tabatabai, 1982), were determined at 50 and 85 days from planting.

Five plants from each replicate were randomly taken at 75 days after planting and the following characteristics were recorded: Plant length (cm), leaf number plant⁻¹, main stem number plant⁻¹, fresh and dry leaves weight (g) plant⁻¹ and fresh and dry stems weight (g) plant⁻¹. Determinations of the macro elements (N, P and K) in leaves were determined according to Martin-Préval *et al.* (1984) and Ibrahim (2010).

At harvest time (120 day after planting), tubers yield of five randomly plants from each experimental plot were taken for estimating the following characteristics: tubers fresh weight (g) plant⁻¹, in addition to both dry matter (%) and starch content of tubers according to A.O.A.C. (1990) and specific gravity (%) as Murphy and Goven (1959). Total yield was determined for each experimental plot at harvest. Total nitrogen was determined in the digested tubers dry matter using micro Kjeldahl method according to methods described by Pregl (1945). Also, phosphorous was estimated according

to the method described by **Murphy and Riley (1962)** modified by **John (1970)** and potassium was determined by the flame-optical method as described by **Brown and Lilleland (1946)**. The crude protein content was calculated by multiplying the nitrogen % in tuber with the conversion factor of 6.25 (**Ranganna, 1977**).

2.5. Statistical Analysis

The obtained data in both seasons of study were subjected to analysis of variance as a simple experiment in a randomized complete block design. LSD ($p \leq 0.05$) was used to evaluate the differences between means according to **Snedecor and Cochran (1980)**.

3. Results and Discussion

Effect of rates of different mineral nitrogen dosages, various organic sources and biofertilizer:

1- Microbial populations in potato rhizosphere

The diversity and density of soil microbial communities are influenced by the quantity and quality of organic and biogenic compounds added to the soil. The results of the study showed that all applied treatments led to a clear increase in the total numbers of bacterial, actinomycetes, and fungi in the rhizosphere of potato plants compared to the control (without inoculation), during the two study seasons (Table 4). The results showed that T4 (75% N + LBM) gave the highest increase in the counts of total bacteria (65 and 71×10^5 cfu/g soil), total actinomycetes (85 and 91×10^3 cfu/g soil) and total fungi (35 and 38×10^3 cfu/g soil) in the rhizosphere while the T1 (control) showed the lowest count of total bacteria (30 and 34×10^5 cfu/g soil), total actinomycetes (44 and 48×10^3 cfu/g soil) and total fungi (13 and 21×10^3 cfu/g soil) in the rhizosphere during the two study seasons respectively. This is probably liquid biogas fertilizer usually provides easily decomposed nutrients such as nitrogen and soluble compounds, which leads to increased microbial proliferation and thus increased numbers and density in the soil. These results are similar to those obtained by **Rondina *et al.* (2020)**, **Farid *et al.* (2023)**, **Hafez *et al.* (2024)** and **Shabana *et al.* (2024)**, they found that the application of liquid organic fertilizers, such as liquid biogas manure and compost tea, have enhanced soil fertility by increasing the number of beneficial microorganisms through enriching the soil with organic matter. Furthermore, the use of biofertilizers, such as *Azospirillum brasilense* increased the total number of microbes in the soil, contributing to improved nutrient availability and stimulating the overall microbial activity of the soil. **Mokhtar *et al.* (2025)** reported that the application of bio and organic fertilizers increases the microbial communities in the rhizosphere, including increased numbers of bacteria, fungi, and actinomycetes. This increase is due to the organic matter serving as a primary substrate for these microorganisms, which supports accelerated cell division and reproduction rates. Also, the combination of bio or organic fertilizers with mineral fertilizers stimulates the growth and reproduction of these microbial communities in the rhizosphere.

2-Enzymes activities in potato rhizosphere

Use the activities of dehydrogenase, phosphatase and nitrogenase enzymes as indicators to estimate microbial activity in soil, especially in the root zone.

Dehydrogenase activity is a very important biomarker of microbial activity in the soil, as the action of this oxidizing enzyme is directly affected by the activity of living microbial cells in the active roots zone. The results in Fig. (1) showed that T4 (75% N + LBM) gave the highest activity of dehydrogenase in the soil, recording 46.14 and 48.09 $\mu\text{g TPF/g dry soil rhizosphere/day}$ in both seasons. This was due to the addition of liquid biogas manure while reducing mineral nitrogen fertilization, which enhanced microbial metabolic activity in the soil. In contrast, the results showed that T1 (control) recorded the lowest dehydrogenase activity in the soil during both seasons. Microbial activity in the root zone is limited by the ability of beneficial microbial communities to multiply and reach high population density. As a result, the efficiency of the dehydrogenase enzyme increases (**Morsy *et al.*, 2021**). The dehydrogenase enzyme found in living cells is an important indicator of soil health and microbial density. Increased activity of this enzyme is directly related to the addition of small amounts of mineral

fertilizers to plants, indicating increased microbial numbers and activity in the soil (Mokhtar *et al.*, 2025).

Table (4). Effect of rates of rates of different mineral nitrogen dosages, various organic sources and biofertilizer on total bacterial, actinomycetes and fungi counts in the rhizosphere of potato during 2023 and 2024 seasons

Treatments	Total Bacterial Counts (10 ⁵ cfu/g soil)			Total Actinomycetes (10 ³ cfu/g soil)			Total Fungi (10 ³ cfu/g soil)		
	2023	2024	Mean	2023	2024	Mean	2023	2024	Mean
T1	30.00	34.00	32.00	44.00	48.00	46.00	13.00	21.00	17.00
T2	42.00	47.00	44.50	67.00	71.00	69.00	22.00	27.00	24.50
T3	56.00	63.00	59.50	77.00	85.00	81.00	29.00	33.00	31.00
T4	65.00	71.00	68.00	85.00	91.00	88.00	35.00	38.00	36.50
T5	37.00	40.00	38.50	61.00	67.00	64.00	19.00	24.00	21.50
T6	49.00	55.00	52.00	71.00	78.00	74.50	28.00	31.00	29.50
T7	52.00	60.00	56.00	72.00	79.00	75.50	24.00	29.00	26.50

T1: 100% N (control), **T2:** 75% N + *Azospirillum brasilense* (BF), **T3:** 75% N + Compost tea (CT), **T4:** 75% N + Liquid biogas manure (LBM), **T5:** 50% N + *Azospirillum brasilense* (BF), **T6:** 50% N + Compost tea (CT), **T7:** 50% N + Liquid biogas manure (LBM).

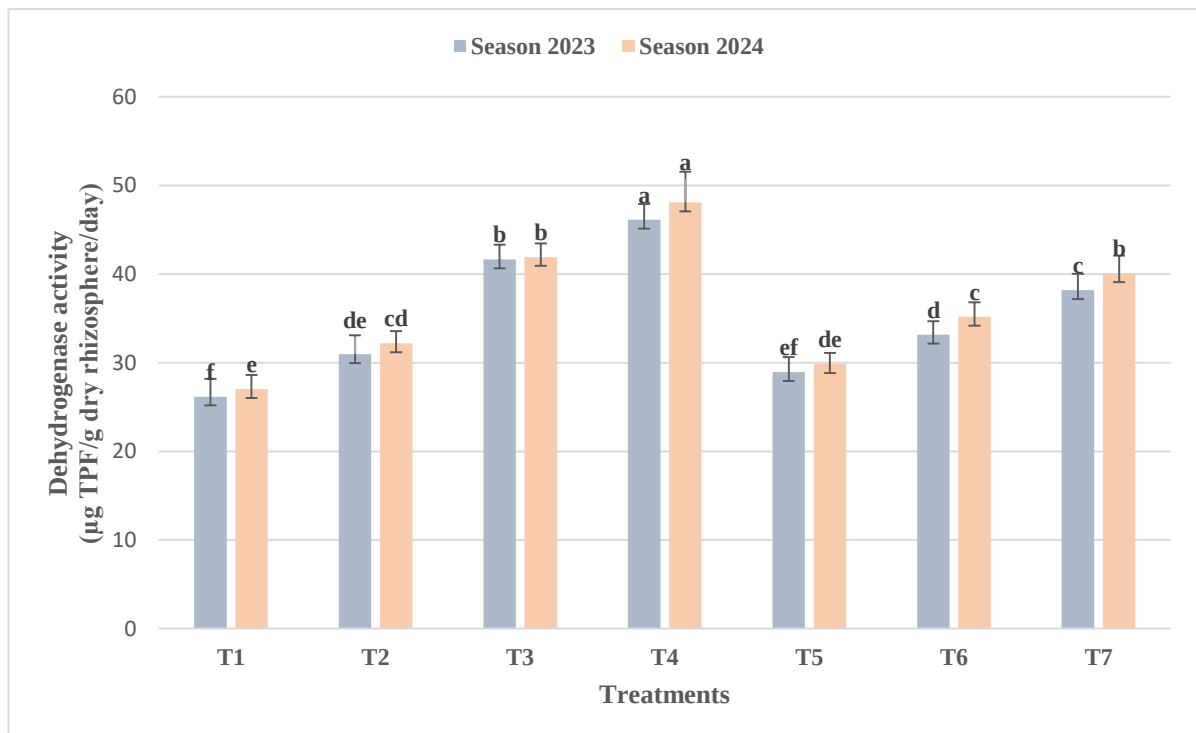


Figure (1). Effect of rates of different mineral nitrogen dosages, various organic sources and biofertilizer on dehydrogenase activity in potato rhizosphere in 2023 and 2024 seasons. Values are means of three replicates $\pm$ standard deviation. Histograms sharing the same letter are not statistically different using LSD test ($p \leq 0.05$)

Phosphatases are great importance in agriculture due to their ability to catalyze the biochemical degradation of organophosphorus compounds. These enzymes convert inorganic phosphates through hydrolysis reactions, ensuring that phosphorus is converted from its bound form into a form that plants and microorganisms can efficiently absorb. Phosphatases thus play a key role in improving phosphorus availability in the soil and supporting the growth of living organisms. Therefore, the results obtained in Fig. (2) indicated that T4 (75% N + LBM) gave the best significant increase in the activity of the phosphatase enzyme in the soil, as it recorded 28.64 and 28.99 mg PNP/g dry soil in both seasons, respectively, compared to all other treatments. This may be due to the presence of liquid biogas fertilizer, which provides organic matter to the soil, leading to increased activity of microbes that secrete phosphatase enzymes that convert organic phosphorus into inorganic phosphorus available for absorption by plant roots. These results are agreement consistent conforming to those presented by **Morsy *et al.* (2021)** and **Mokhtar *et al.* (2025)**. They found a direct relationship between phosphatase activity and the availability of organic matter.

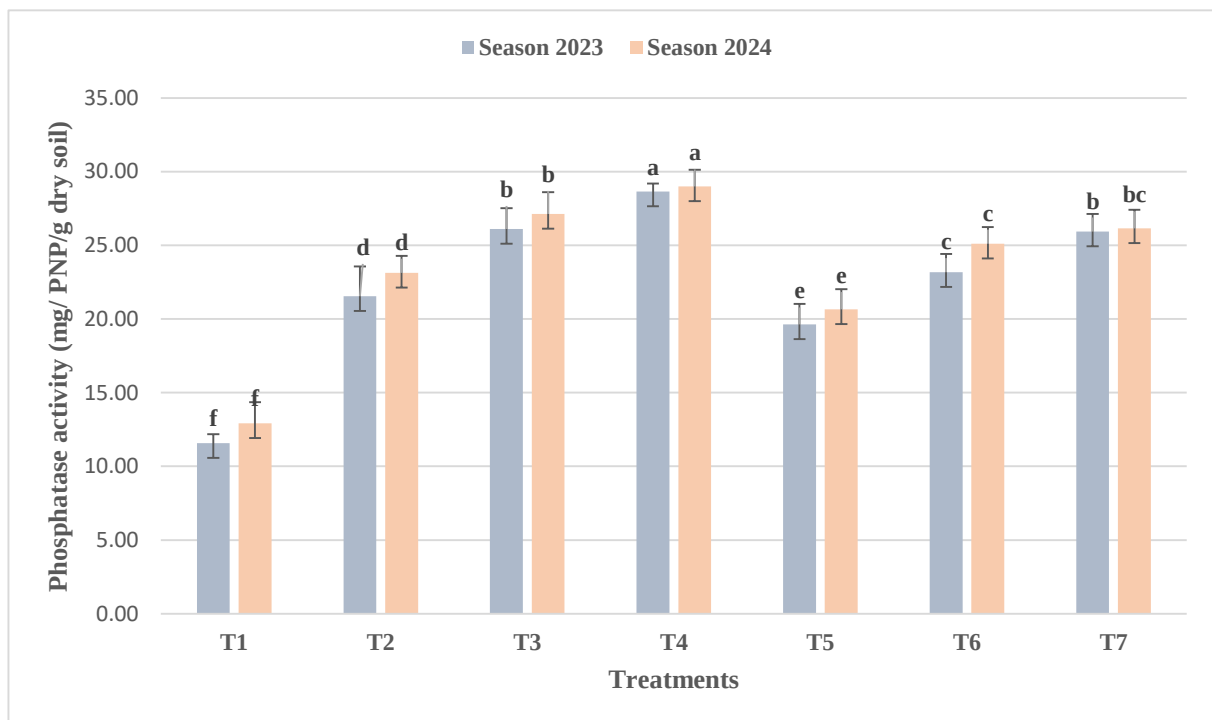


Figure (2). Effect of rates of different mineral nitrogen dosages, various organic sources and biofertilizer on phosphatase activity in potato rhizosphere in 2023 and 2024 seasons. Values are means of three replicates $\pm$ standard deviation. Histograms sharing the same letter are not statistically different using LSD test ($p \leq 0.05$)

Nitrogenase activity was associated with the viability of non-symbiotic nitrogen-fixing bacteria added to the treatments. Therefore, the results obtained in Fig. (3) showed that T2 (75% N + BF) gave the highest significant increase in nitrogenase activity, recording 97.23 and 99.63 $\mu\text{mol C}_2\text{H}_4/\text{g dry rhizosphere/h}$ in both seasons, respectively. This may be due to the presence of *Azospirillum brasilense* increase atmospheric nitrogen fixation using low doses of mineral nitrogen fertilizer, which leads to increased nitrogenase activity in the soil. In contrast, it was observed that T1 (Control) gave the least significant increase in nitrogenase activity. This may be due to the presence of large amounts of mineral nitrogen fertilizer gave feedback inhibitor for nitrogenase enzymes. These results are in agreement with **Morsy *et al.* (2021)**, **Sinha *et al.* (2024)** and **Mokhtar *et al.* (2025)**; they found that nitrogenase activity in soil increased with the addition of biofertilizers with reducing the amount of mineral nitrogen fertilizer.

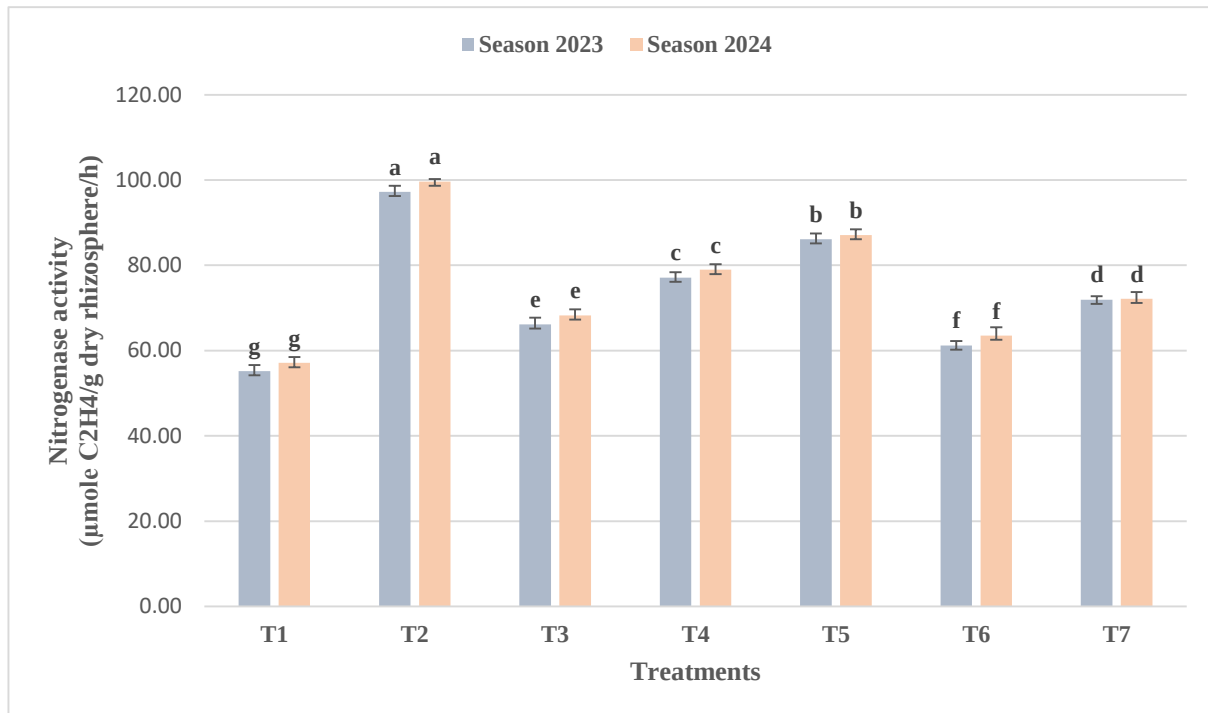


Figure (3). Effect of rates of different mineral nitrogen dosages, various organic sources and biofertilizer on nitrogenase activity in potato rhizosphere in 2023 and 2024 seasons. Values are means of three replicates $\pm$ standard deviation. Histograms sharing the same letter are not statistically different using LSD test ($p \leq 0.05$)

3-Vegetative growth parameters

Data in Tables (5 and 6) clearly show the effect of reducing chemical nitrogen fertilizers with added organic and biofertilizer treatments on vegetative growth characteristics of potato plant at 75 day after planting during the two growing seasons of 2023 and 2024 compared with the T1 (control). In this respect, the T4 treatment (75% N + LBM) followed by T3 (75% N + CT) and T2 (75% N + BF) recorded the highest values of vegetative growth parameters of potato plant. The addition of T4 (75% N + LBM) scored the highest significant increase in plant length and number of leaves during the two successive seasons. On the other hand, T4 treatment (75% N + LBM) scored the highest significant increase in number of stems during the second season only. While, there was no significant differences among different treatments in first season.

As for leaves, stems and plant fresh weight obtained data revealed that T4 (75% N + LBM), T3 (75% N + CT) and T2 (75% N + BF) treatments gave the highest significant increase in both characters than other treatments in during two seasons. As shown in Table (6), data revealed that T4 (75% N + LBM), T3 (75% N + CT) and T2 (75% N + BF) gave the highest significant increase in leaves, stems and plant dry weight in both seasons. The obtained results could be related to the enhancement role of adding organic fertilizers (LBM, CT and BF) combining with reducing nitrogen fertilizers which reveals on encouragement of the microbial communities in potato plants rhizosphere (Table1, Fig. 4 and Fig 1, 2 and 3). These results are in line with those obtained by **Shabana *et al.* (2024)**.

Table (5). Effect of rates of different mineral nitrogen dosages, various organic sources and biofertilizer on plant Length, leaves number and stems number of potato plants at 75 days from planting during 2023 and 2024 seasons

Treatments	Plant Length (cm)		Leaves Number		Stems Number	
	2023	2024	2023	2024	2023	2024
T1	49.00 c	62.67 bc	35.33 d	54.50 a	2.50 ab	1.33 bc
T2	56.00 ab	59.57 d	45.00 b	55.33 a	3.00 a	1.33 bc
T3	55.00 b	62.33 c	45.00 b	55.00 a	2.25 b	1.00 c
T4	56.50 a	68.60 a	56.00 a	56.00 a	2.50 ab	2.00 a
T5	50.00 c	64.83 b	40.00 c	54.72 a	2.50 ab	1.33 bc
T6	47.00 d	63.67 bc	30.50 e	56.00 a	2.50 ab	1.56 ab
T7	49.27 c	57.83 d	40.67 c	51.50 b	2.50 ab	2.00 a
LSD (0.05)	1.32	2.35	2.05	2.71	NS	0.54

T1: 100% N (control), **T2:** 75% N + *Azospirillum brasilense* (BF), **T3:** 75% N + Compost tea (CT), **T4:** 75% N + Liquid biogas manure (LBM), **T5:** 50% N + *Azospirillum brasilense* (BF), **T6:** 50% N + Compost tea (CT), **T7:** 50% N + Liquid biogas manure (LBM). Means in the same column sharing the same letter are not statistically different using LSD test ($p \leq 0.05$).

Table (6). Effect of rates of different mineral nitrogen dosages, various organic sources and biofertilizer on fresh and dry weight of leaves, stems and potato plant at 75 days from planting during 2023 and 2024 seasons

Treatments	Leaves F.W. (g)		Stems F.W. (g)		Plant F.W. (g)		Leaves D.W. (g)		Stems D.W. (g)		Plant D.W. (g)	
	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024
T1	147.00 cd	166.83 b	41.25 d	75.50 b	188.25 cd	242.00 c	22.95 bc	19.15 c	3.33 e	7.56 b	26.27 c	26.71 c
T2	156.90 bc	208.00 a	48.50 c	61.33 d	205.38 bc	269.17 b	21.05 c	24.65 b	4.68 b	7.15 bc	25.72 c	31.80 b
T3	174.17 ab	194.00 a	52.00 b	73.17 bc	226.17 ab	267.17 b	24.68 b	24.32 b	4.35 c	8.87 a	29.03 b	33.19 b
T4	190.00 a	209.00 a	57.00 a	83.67 a	247.00 a	292.67 a	28.16 a	26.66 a	6.03 a	8.94 a	34.19 a	35.60 a
T5	141.00 cd	131.33 c	37.50 e	49.50 e	178.50 de	180.75 e	22.37 c	15.18 d	4.06 cd	5.11 d	26.43 c	20.29 d
T6	124.67 d	134.83 c	32.25 f	47.25 e	156.92 e	182.00 e	18.37 d	16.50 d	3.06 e	4.45 d	21.43 d	20.95 d
T7	152.27 bc	148.33 bc	43.00 d	69.75 c	195.25 cd	218.00 d	18.42d	20.25 c	3.81 d	6.75 c	22.22 d	27.00 c
LSD (0.05)	27.02	24.85	3.37	5.17	26.54	22.42	2.19	1.73	0.29	0.70	2.14	1.97

T1: 100% N (control), **T2:** 75% N + *Azospirillum brasilense* (BF), **T3:** 75% N + Compost tea (CT), **T4:** 75% N + Liquid biogas manure (LBM), **T5:** 50% N + *Azospirillum brasilense* (BF), **T6:** 50% N + Compost tea (CT), **T7:** 50% N + Liquid biogas manure (LBM). Means in the same column sharing the same letter are not statistically different using LSD test ($p \leq 0.05$).

These findings are quite intriguing because several applied treatments had significant simulative effects at growth stage. This could therefore be extended to the advanced stage of the yield and quality of tubers that are ultimately produced. Additionally, as previously indicated, a growth in the number of leaves results in an increase in the fresh and dry weights of shoots (stems and leaves). By accumulating more assimilates and exhibiting high rates of their translocation, particularly toward developed tubers, an increase in the number of leaves may indicate an improvement in photosynthetic efficiency. Liquid biogas manure and compost tea are abundant sources of nutrients and organic matter. They improve soil structure, increase soil fertility, and give plants vital nutrients when applied to the soil. Over time, organic matter boosts microbial activity, acts as a nutrient storage, and makes nutrients more accessible

to plants. These organic fertilizers' capacity to provide nutrients and enhance soil health is what makes them so successful at encouraging plant growth (Ai *et al.*, 2020, Møller *et al.*, 2022, Farid *et al.*, 2023, Nada *et al.*, 2023, Hafez *et al.*, 2024, Shabana *et al.*, 2024, Mokhtar *et al.*, 2025 and Taha *et al.*, 2025). *Azospirillum brasilense* colonizes the Rhizosphere and establishes a symbiotic relationship with the roots of plants after being inoculated onto them. Consequently, it increases the plants' availability of nitrogen, improving growth metrics including yield, plant height, and leaf count (Galindo *et al.*, 2022).

4- Nutritional status of the leaves

Adding liquid biogas manure, biofertilizer (*Azospirillum brasilense*) or compost tea with mineral nitrogen fertilizer at a rate of 75% of the recommended dose led to a significant improvement in the concentration of N, P, and K in the leaves compared to the control (Table 7). Furthermore, T4 (75% N + LBM) gave the highest significant increase in N, P, and K, where N recorded 3.35 and 3.41 %, P recorded 0.43 and 0.49 % and K recorded 3.09 and 3.15 % in both seasons, respectively. On the other hand, the results showed that T6 (50% N + CT) gave the lowest leaves concentration of N, P, and K during the two seasons respectively. This may be because liquid biogas fertilizer contains a high concentration of macro elements that are easily absorbed by plant roots. Although *Azospirillum brasilense* fix atmospheric nitrogen, liquid biogas manure was superior to them. This is because liquid biogas manure contains nitrogen-fixing bacteria, phosphate-solubilizing bacteria, potassium-facilitating bacteria, amino acids, organic acids such as humic substances, peptides, growth regulators, and stimulating hormones (Taha *et al.*, 2025). Zaheer *et al.* (2022) found that using *Azospirillum brasilense* as a bioinoculant significantly increased both leaf chemical content and nitrogen uptake rates. This is due to the bacteria's role in fixing atmospheric nitrogen and facilitating the uptake of other nutrients by plants. The superiority of liquid biogas manure is due to its rich content of elements and soil improving properties, which enhance the availability and absorption (Nada *et al.*, 2023, Abd ELhamied *et al.*, 2024, Hafez *et al.*, 2024 and Shabana *et al.*, 2024).

Table (7). Effect of rates of different mineral nitrogen dosages, various organic sources and biofertilizer on chemical constituents in leaves of potato at 75 days from planting during 2023 and 2024 seasons

Treatments	N (%)		P (%)		K (%)	
	2023	2024	2023	2024	2023	2024
T1	3.08 c	3.14 cd	0.37 ab	0.39 a	2.79 bc	2.87 b
T2	3.25 b	3.32 ab	0.40 ab	0.43 ab	2.99 a	3.10 a
T3	3.11 c	3.19 bc	0.38 ab	0.41 ab	2.82 b	2.93 b
T4	3.35 a	3.41 a	0.43 a	0.49 a	3.09 a	3.15 a
T5	3.01 d	3.09 cd	0.36 ab	0.38 b	2.71 cd	2.75 c
T6	2.84 f	2.88 e	0.34 b	0.36 b	2.61 d	2.67 c
T7	2.92 e	2.99 de	0.35 ab	0.37 b	2.68 d	2.71 c
LSD (0.05)	0.06	0.16	NS	NS	0.11	0.11

T1: 100% N (control), **T2:** 75% N + *Azospirillum brasilense* (BF), **T3:** 75% N + Compost tea (CT), **T4:** 75% N + Liquid biogas manure (LBM), **T5:** 50% N + *Azospirillum brasilense* (BF), **T6:** 50% N + Compost tea (CT), **T7:** 50% N + Liquid biogas manure (LBM). Means in the same column sharing the same letter are not statistically different using LSD test ($p \leq 0.05$).

5- Yield and its components

The data presented in Table (8) clearly indicate that the yield of tubers and their components in potatoes significantly varies due to the rates of different mineral nitrogen dosages, various organic sources and biofertilizer applied. T4 (75% N + LBM) gave the maximum significant increase in tuber

fresh weight per plant and tuber yield per feddan during the first seasons. Also, in the second season T4 (75% N + LBM), T3 (75% N + CT) and T2 (75% N + BF) produced the highest total yield. Furthermore, T4 (75% N + LBM) and T3 (75% N + CT) gave the highest dry matter of tuber during the first and second season, respectively. While, there was no significant differences among different treatments in tubers specific gravity during the first and second seasons.

Table (8). Effect of rates of different mineral nitrogen dosages, various organic sources and biofertilizer on tubers fresh weight (g plant), tubers dry matter (D.M.) %, tubers specific gravity and tubers total yield (ton) feddan⁻¹ of potato plant during 2023 and 2024 seasons

Treatments	Tubers fresh weight (g plant)		Tubers dry matter %		Tubers specific gravity		Tubers total yield (ton /feddan)	
	2023	2024	2023	2024	2023	2024	2023	2024
T1	765.78 c	817.68 b	20.87 b	19.81 b:d	1.083 a	1.078 bc	16.319 d	17.989 b
T2	803.88 b	854.00 a	20.16 cd	20.17 bc	1.079 a	1.077 bc	17.330 c	18.788 a
T3	809.79 b	821.72 b	20.71 bc	20.97 a	1.080 a	1.082 a	18.092 b	18.078 b
T4	846.00 a	862.20 a	21.76 a	20.29 b	1.084 a	1.080 ab	18.693 a	18.968 a
T5	625.34 d	625.47 c	20.20 cd	19.80 b:d	1.080 a	1.078 bc	13.894 e	13.760 c
T6	587.84 e	543.20 e	20.32 b:d	19.67 cd	1.080 a	1.077 bc	13.545 f	11.950 e
T7	619.26 d	595.47 d	19.90 d	19.33 d	1.080 a	1.077 c	14.110 e	13.100 d
LSD (0.05)	12.35	19.97	0.59	0.59	NS	NS	0.218	0.581

T1: 100% N (control), **T2:** 75% N + *Azospirillum brasilense* (BF), **T3:** 75% N + Compost tea (CT), **T4:** 75% N + Liquid biogas manure (LBM), **T5:** 50% N + *Azospirillum brasilense* (BF), **T6:** 50% N + Compost tea (CT), **T7:** 50% N + Liquid biogas manure (LBM). Means in the same column sharing the same letter are not statistically different using LSD test ($p \leq 0.05$).

Furthermore, liquid biogas manure and compost tea may have caused a slow supply of micro and macro elements throughout the potato growth period. This positively impacted vegetative growth criteria and leaf nutrient content as well as the yield and quality of tubers and soil content of available nitrogen, phosphorus, potassium, and organic matter at harvest. The obtained results are in harmony with those of **Wilson *et al.* (2019)** and **El-Ghamry *et al.* (2025)**. Same results were obtained by **Galindo *et al.* (2022)**, **Zaheer *et al.* (2022)** and **Shabana *et al.* (2024)**, they found that the treatment with *Azospirillum brasilense* enhances nitrogen availability to the plants, leading to improved growth parameters such plant height, and leaf number let to a higher yield.

6- Nutritional status of the tubers of potato plants

Data in table (9) display effect of rates of different mineral nitrogen dosages, various organic sources and biofertilizer on chemical constituents in tuber of potato at period of 120 days from planting of potato during 2023 and 2024 seasons. The results clearly showed that adding liquid biogas manure, compost tea or biofertilizer (*Azospirillum brasilense*) with a mineral nitrogen fertilizer rate of 75% of the recommended dose led to a significant increase in the tubers N, P, K and crude protein content. As the results showed that T4 (75% N + LBM) gave the highest significant increase in the concentration of N, P, K and total protein in tubers, where N recorded 2.51 and 2.55 %, P recorded 0.44 and 0.47 %, K recorded 2.47 and 2.49 % and crude protein recorded 15.69 and 15.94 % during the two consecutive study seasons compared to all other treatments. On the other hand, T6 (50% N + CT) produced tubers containing the lowest concentration of N, P, K and total protein in both seasons. However, the results obtained in Fig. (4) showed that T1 (100% N) and T3 (75% N + CT) gave the highest in starch percentage in the potato tubers during the first and second season, respectively. The obtained results could be due to the effective role played by liquid biogas manure and compost tea in providing the elements needed by the plant and improving the physical, chemical and microbiological properties of the soil. These results are agreement consistent conforming to presented by **Elshaboury *et al.* (2024)**, **Shaban *et al.* (2025)**, **Abdel Motaleb, *et al.* (2025)** and **El-Ghamry *et al.* (2025)**, they found that organic fertilizers improve soil properties, providing the macro and micro elements needed by plants in readily available

forms that are slowly available to the plant during the growth period. This leads to increased productivity, improved tuber quality, and increased nitrogen, phosphorus, potassium, crude protein and starch content in tuber. **Abou El-Goud and Yousry (2021)** found that the use of compost tea in fertilizing potatoes led to an increase in the production of enzymes, active substances, hormones, and antibiotics, which led to an increased the percentage of starch, total sugars, and total soluble solids in potato tubers.

Table (9). Effect of rates of different mineral nitrogen dosages, various organic sources and biofertilizer on chemical constituents in tuber of potato at 120 day from planting during 2023 and 2024 seasons

Treatments	N (%)		P (%)		K (%)		Crude protein (%)	
	2023	2024	2023	2024	2023	2024	2023	2024
T1	2.31 cd	2.34 d	0.40 ab	0.43 a	2.39 a:d	2.41 a:c	14.44 cd	14.63 d
T2	2.45 ab	2.47 b	0.42 ab	0.44 a	2.43 ab	2.46 ab	15.31 ab	15.44 b
T3	2.39 bc	2.42 c	0.41 ab	0.43 a	2.41 a:c	2.42 a:c	14.94 bc	15.13 c
T4	2.51 a	2.55 a	0.44 a	0.47 a	2.47 a	2.49 a	15.69 a	15.94 a
T5	2.25 de	2.27 e	0.39 ab	0.41 a	2.35 b:d	2.38 bc	14.06 de	14.19 e
T6	2.09 f	2.15 g	0.36 b	0.38 a	2.29 d	2.33 c	13.07 f	13.44 g
T7	2.17 ef	2.20 f	0.38 ab	0.39 a	2.31 cd	2.33 c	13.56 ef	13.75 f
LSD (0.05)	0.12	0.03	NS	NS	0.11	0.09	0.74	0.22

T1: 100% N (control), **T2:** 75% N + *Azospirillum brasilense* (BF), **T3:** 75% N + Compost tea (CT), **T4:** 75% N + Liquid biogas manure (LBM), **T5:** 50% N + *Azospirillum brasilense* (BF), **T6:** 50% N + Compost tea (CT), **T7:** 50% N + Liquid biogas manure (LBM). Means in the same column sharing the same letter are not statistically different using LSD test ($p \leq 0.05$).

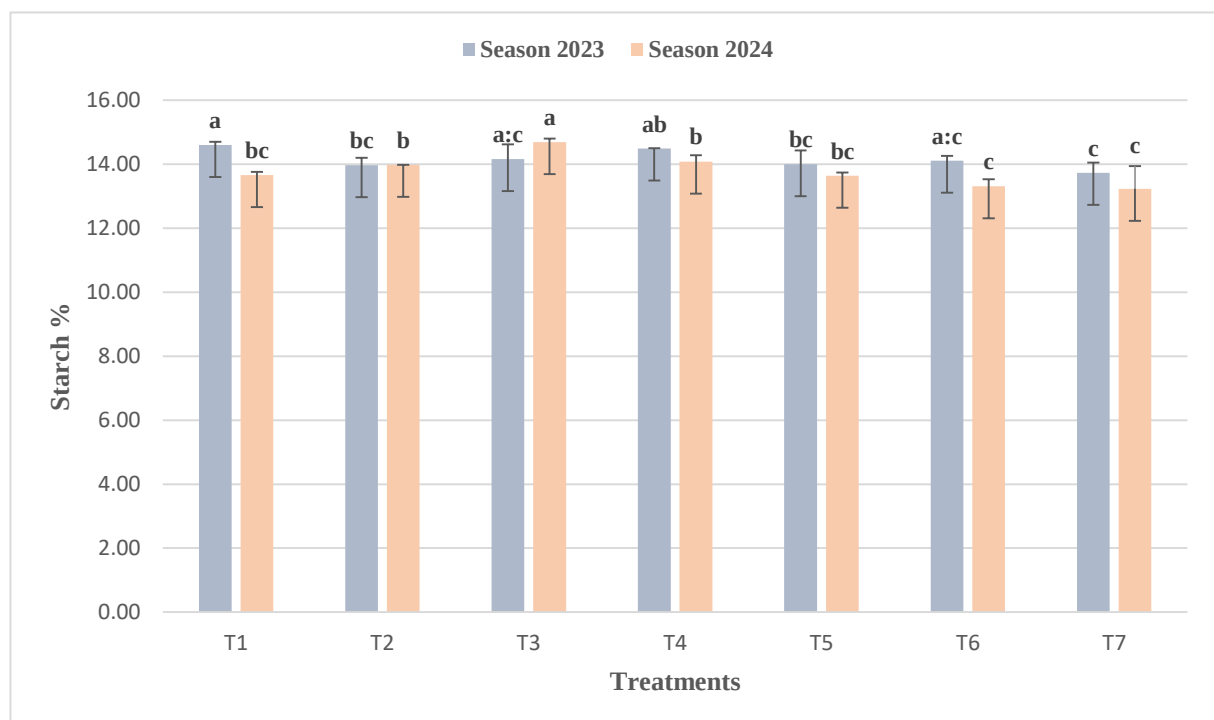


Figure (4). Effect of rates of different mineral nitrogen dosages, various organic sources and biofertilizer on starch percentage in potato tubers in 2023 and 2024 seasons. Values are means of three replicates $\pm$ standard deviation. Histograms sharing the same letter are not statistically different using LSD test ($p \leq 0.05$)

7- Analysis of available macronutrients in soil postharvest

Data in table (10) illustrates the effect of rates of different mineral nitrogen dosages, various organic sources and biofertilizer on available macronutrients (N, P and K) in soil after 120 days from planting of potato during 2023 and 2024 seasons. The results obtained in the table show that the use of liquid biogas manure, compost tea, or biofertilizer (*Azospirillum brasilense*) with 75% of the recommended dose of mineral nitrogen had a positive effect in increasing the levels of N, P, and K in the soil after harvest. Consistent trends were evident in both seasons. This is probably because organic fertilizers (liquid biogas manure and compost tea) increase soil fertility, improve soil structure, and support the growth of beneficial microbes. Meanwhile, biofertilizers, through their microorganisms, help fix atmospheric nitrogen and increase its levels, in addition to dissolving and releasing other nutrients to enhance the soils nutritional efficiency. The results also showed that T4 (75% N + LBM) gave the highest levels of N, P, and K in the soil, where N recorded 82.09 and 82.96 mg kg⁻¹, P was recorded 4.61 and 4.65 mg kg⁻¹ while K recorded 87.96 and 88.26 mg kg⁻¹ in both seasons compared to other treatments. In contrast, the results indicated that T6 (50% N + CT) recorded the lowest increase in N, P and K levels in the soil in both seasons. These results are similar with those obtained by by **Shabana et al. (2024)**, **Elshaboury et al. (2024)**, **Shaban et al. (2025)**, **Abdel Motaleb, et al. (2025)**, **Taha, et al. (2025)** and **El-Ghamry et al. (2025)**. They found similar results to the ones mentioned.

Table (10). Effect of rates of different mineral nitrogen dosages, various organic sources and biofertilizer on available macronutrients on soil at 120 days from planting during 2023 and 2024 seasons

Treatments	N (mg kg ⁻¹)		P (mg kg ⁻¹)		K (mg kg ⁻¹)	
	2023	2024	2023	2024	2023	2024
T1	76.03 c	77.21 c	4.44 a	4.48 a	79.66 d	80.71 d
T2	79.67 b	80.05 b	4.56 a	4.58 a	85.03 b	86.14 b
T3	77.09 c	78.73 b	4.51 a	4.54 a	81.66 c	81.97 c
T4	82.09 a	82.96 a	4.61 a	4.65 a	87.96 a	88.26 a
T5	73.25 d	74.66 d	4.39 a	4.41 a	77.21 e	78.14 e
T6	67.24 f	67.95 f	4.25 a	4.30 a	72.18 g	73.15 g
T7	69.18 e	70.03 e	4.33 a	4.37 a	75.13 f	76.71 f
LSD (0.05)	1.10	1.51	NS	NS	1.43	0.80

T1: 100% N (control), **T2:** 75% N + *Azospirillum brasilense* (BF), **T3:** 75% N + Compost tea (CT), **T4:** 75% N + Liquid biogas manure (LBM), **T5:** 50% N + *Azospirillum brasilense* (BF), **T6:** 50% N + Compost tea (CT), **T7:** 50% N + Liquid biogas manure (LBM). Means in the same column sharing the same letter are not statistically different using LSD test ($p \leq 0.05$).

4. Conclusion

The study results cleared that liquid biogas manure, compost tea, or *Azospirillum brasilense* increased growth and nitrogen uptake in potato plants, as well as increasing microbial populations, enzyme activity, and yield when applied with 75% doses of mineral nitrogen fertilizer. Using liquid biogas fertilizer integration with mineral nitrogen fertilizer at 75% of the recommended dose improved growth, yield, and yield components. Liquid biogas manure, compost tea, or *Azospirillum brasilense* can be recommended as promising alternatives to reduce reliance on mineral nitrogen fertilizers in potato cultivation.

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