Effect of Integrated Mineral and Bio-fertilizers on Onion (*Allium fistulosum*) Growth and Soil Nutrient Status

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ABSTRACT

Onion (*Allium cepa* L.) is an important crop in Egypt that requires fertilizer to improve yield and soil health in low-organic-matter soils. At Damanhour University, experiment farm at Agriculture faculty, this study assessed the effects of mineral fertilizer and bio-fertilizers (Nitrobeine, Phosphorene) combinations on soil fertility, growth, and nutrient content of green onions (*Allium fistulosum* L.) in loamy sand soil during the 2022–2023 and 2023–2024 seasons. Using a Completely Randomized Design with three replicates, treatments included control (CK), NPK, Nitrobeine (bioN), Phosphorene (bioP), mixed bio-fertilizers (bioN-P), NPK&bioN, NPK&bioP, NPK&bioN-P, 0.5NPK&bioN-P, and 0.75NPK&bioN-P. Vegetative growth characteristics, plant chlorophyll content (SPAD), plant and soil nutrients contents were measured. Fresh weight of the plant (33.03 g), dry stem weight (8.97 g), plant content of N (3.18%), K (3.43%), soil content of N (26.95 ppm), P (11.05 ppm), and K (119.25 ppm) were all maximized by the NPK&bioN-P treatments. Similar result was achieved with fresh weight (32.23 g) and root/leaf growth with application of the 0.5NPK&bioN-P treatments, suggesting that yield was maintained at 50% lower NPK when combined with bio-fertilizers. While soil P grew (6.93, 14.67 and 13.60% consecutively) with bio-fertilizers-only treatments (bioN, bioP, and bioN-P). For increasing onion productivity in Egypt, integrated nutrition management provides a sustainable approach, especially for NPK&bioN-P and 0.5NPK&bioN-P.

Keywords: Green onion, bio-fertilizers, mineral fertilizer, Macronutrients, Nitrobeine, Phosphorene.

INTRODUCTION

Egypt produces large quantities of onions (*Allium cepa*), the production capacity of the onion crop is estimated at 1681.08 thousand tons during the average period (2001-2017) at Abu Zeid *et al.* (2019). Onions are vital to the national and international markets (Khalaf *et al.,* 2020). Onions should be grown using nutrient management methods to improve their quality and productivity (Abdelkader *et al.,* 2022). Balanced NPK application in soil conditions is essential for maximum onion production (El-Sheref *et al.,* 2023; Wu *et al.,* 2023 and ElGhamry *et al.,* 2024). Bio-fertilizers contain living microorganisms that promote plant growth by increasing macronutrients and other essential elements availability (Mushtaq *et al.,* 2020 and Aloo *et al.,* 2022). Nitrobeines is a commercial nitrogenous bio-fertilizer that contains bacteria (*Azotobacter choroccocum*) that free-living nitrogen-fixing bacteria, that enhances early seed germination and promotes root development (Younis *et al.,* 2009 and Salim & Shehata, 2025b). Studies have found that treating onion seeds with Nitrobeine increases root length, seedling height, plant height, number of leaves per plant, leaf length, and leaf thickness (Singh *et al.,* 2020 and Salim & Shehata, 2025b). Phosphorene, often used as a commercial term for phosphate-solubilizing microbes (PSMs) including bacteria (*Bacillus megaterium*), plays a crucial role in enhancing plant growth and yield (Salim *et al.,* 2025a). PSMs convert insoluble phosphorus in the soil into soluble forms that can be easily absorbed by plants (Soumare *et al.,* 2020). Phosphorene significantly was found to improve onion growth and productivity (Khan *et al.,* 2023). It enhanced onion root development, improved seedling vigor, increased leaf area and increased chlorophyll content (Singh *et al.,* 2020 and Salim *et al.,* 2025a). Nitrobeine and Phosphorene are two widely used bio-fertilizers in Egypt that improve access of nitrogen (N) and phosphorus (P) to crops via microbial activities (El-Gioushy, 2016; Salim *et al.,* 2025a and Salim & Shehata, 2025b). When applied together, these bio-fertilizers complement each other by improving N and P nutrition, which are critical during the early growth and bulb development stages of onions (Ghodia, 2012). The integrated use of Nitrobeine + Phosphorene with reduced chemical fertilizers doses can achieve yields similar to full NPK application (Baiea *et al.,* 2018 and El-Badawy *et al.,* 2020). Integrated Nutrient Management (INM) combines the use of mineral fertilizers and bio-fertilizers to optimize nutrient supply, soil fertility, soil health, crop productivity. It reduces environmental pollution, and increase farmers' economic incomes (Panta and Parajulee 2021). In onion cultivation, INM plays a vital role in ensuring balanced nutrition (Gebremichael *et al.,* 2017 and Gnanasundari *et al.,* 2022). This study aimed to evaluate the effects of integrated nutrient management (mineral fertilizers & bio-fertilizers) on nutrients' content, soil nutrient content and the green onion (*Allium fistulosum* L.) growth

DOI: 10.21608/asejaiqjsae.2025.448018

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Received July 15, 2025, Accepted, August 16, 2025

cultivated in loamy sand soil during the 2022-2023 and 2023-2024 seasons at Damanhour University, experimental farm.

MATERIAL AND METHODS

Two experiments were conducted to cultivate green onions in pots (it was about 15 cm in diameter, 20 cm high, and contained 3 kg of soil) during the 2022-2023 and 2023-2024 seasons at experimental farm, the Faculty of Agriculture, Damanhour University. This study aimed to investigate the effects of combinations of NPK fertilizers and bio-fertilizers applications (Nitrobeine and Phosphorene) on the green onion's growth. The soil was chemically analyzed according to Jones (2018). The initial soil sample properties were pH (7.51), EC (1.9 ds/m), available nitrogen (31.5 ppm), available phosphorus (7.5 ppm), available potassium (47.2 ppm), and organic matter (0.2%). The experimental treatments were as follows: control (CK), recommended mineral fertilizers (NPK), Nitrobeine bio-fertilizers (bioN), Phosphorene bio-fertilizers (bioP), mixed bio-fertilizers (bioN-P), recommended mineral fertilizers and Nitrobeine bio-fertilizers (NPK&bioN), recommended mineral fertilizers and Phosphorene bio-fertilizers (NPK&bioP), integrated mineral fertilizers and bio-fertilizers (NPK&bioN-P), half mineral fertilizers and bio-fertilizers (0.5 NPK&bioN-P), and three-quarters of the mineral fertilizers with bio-fertilizers (0.75 NPK&bioN-P). The recommended dose of NPK fertilizer was added (500 kg ammonium sulfate, 500 kg calcium superphosphate, and 200 kg potassium sulfate per fadan), as reported by El-Desuki *et al.* (2006). Giza white onion seedlings (2 seedling per pot) were planted from the beginning of November and harvested on December 20 to measure vegetative characteristics and take soil and plant samples for analysis. Fertilizers were added according to each treatment with soil preparation for planting and irrigation was carried out every 2-3 days to maintain soil moisture without saturation. Nitrobeine and Phosphorene bio-fertilizers are commercial products that contain active microorganisms. Bio-fertilizers were added according to Abo-Sedera *et al.* (2012) at a rate of 10 g per pot (10g/3Kg soil). Nitrobeine and Phosphorene were obtained from the General Organization for Agriculture Equalization Fund (GOAEF), Ministry of Agriculture, Egypt. A Completely Randomized Design (CRD) with three replicates was followed. After the first and second seasons, the vegetative characteristics of the green onion plants were measured as follows: plant length, leaf number, fresh weight, fresh leaf weight, steam fresh weight, root weight, root length, stem diameter, leaf diameter, leaf length, dry root weight, dry leaf weight, and dry steam weight. Chlorophyll content was determined using a SPAD-portable Chlorophyll meter (Spectrum Technologies, Inc., Aurora, Illinois, USA) (Süß *et al.*, 2015). The nitrogen, phosphorus, and K contents of the green onion leaves were measured after drying the leaves (Pal, 2019). And in soil, available nitrogen, available phosphorus, and available potassium were also measured (Jones, 2018).

Statistical Analysis:

One-way analysis of variance (ANOVA) with three replicates per treatment was used to examine the effects of the treatments. The obtained data were statistically analyzed, and the LSD was calculated at 5% significance level using the Costat software (1985) (version 6.4).

RESULTS AND DISCUSSION

The first season results showed that the combination of mineral fertilizers with bio-fertilizers (Nitrobeine and Phosphorene) significantly improved green onion growth (Table 1). Plant height (48.7 cm), number of leaves (5.67), stem diameter (1.44 cm), and leaf diameter (1.03 cm) were the highest for the combined treatment (NPK&bioN-P). Reducing mineral fertilizer inputs while maintaining bio-fertilizers use can still support healthy plant development, as evidenced by the (0.5NPK&bioN-P) treatment, which achieved the maximum root length (19.38 cm) and leaf length (35.33 cm). The second growing season results supported the first season results, which showed that green onion growth parameters were significantly enhanced by integrated nutrition management. The (0.5NPK&bioN-P) treatments produced the longest plant length (47.42 cm), root length (19.32 cm), and leaf length (35.33 cm), suggesting that growth can be maintained by half mineral fertilizer inputs with bio-fertilizers. In contrast, NPK and bioN-P treatments resulted in the thickest stems (1.45 cm) and the largest leaf diameter (0.98 cm). Green onion growth was significantly improved in both seasons by combining mineral fertilizers with Nitrobeine and Phosphorene bio-fertilizers treatments, particularly NPK, bioN-P and 0.5NPK&bioN-P. Significantly, the 0.5NPK&bioN-P treatments continuously promoted the greatest root length and leaf elongation. These findings support the possibility of using bio-fertilizers to lower chemical inputs, while preserving productivity. These results are in agreement with those reported by Kandil *et al.* (2011); Kandil *et al.* (2013) and Geisseler *et al.* (2022). A high N rate with bio-fertilizer treatment significantly increased the vegetative characteristics of onion (*Allium cepa* L.). Plant height and vegetative characteristics compared to N alone owing to enhanced nutrient content (Hafez and Geries, 2018). Arunachalam *et al.* (2024) evaluated phosphorus-solubilizing bacteria effect with 50% or 100% recommended dose of fertilizers on onions, which

increased plant height and vegetative characteristics compared to the recommended fertilizer dose alone. Zhang *et al.* (2025) reported the N bio-fertilizers application reduced mineral fertilizers (75% NPK) in onions and increased onion vegetative characteristics compared to 100% NPK.

Table (2) showed the effects of minerals and bio-fertilization on the vegetative characteristics (Fresh and Dry weight) of green onion plants. The first-season results showed that the combination of mineral fertilizers and bio-fertilizers (Nitrobeine and Phosphorene) significantly enhanced fresh and dry weights. Fresh weight (33.03 g), fresh leaves (31.92 g), fresh stems (51.64 g), and dried stems (8.97 g) were the highest in the combined treatment (full recommended doses of NPK with bio-fertilizers). This suggests that the overall plant vigor and productivity were improved by the combined application. The (0.5NPK&bioN-P) treatment also performed well.

The results of the second growing season supported the first season's development, showing that green onion biomass and yield were greatly increased by the integrated nutrient management. Strong vegetative development was indicated by the NPK&bioN-P treatments, which consistently produced the highest fresh leaves (32.96 g), fresh stems (51.68 g), and dry leaves (3.04 g). The (0.5NPK& bioN-P) had the highest total fresh weight (32.23 g). The (NPK&bioN-P) treatment was the most effective in both seasons. Nevertheless, in the second season, the (0.5 NPK&bioN-P) demonstrated competitive biomass yields and exceeded all other treatments in terms of fresh weight (32.23 g). This finding suggests that bio-fertilizers can reduce the mineral fertilizers use. The (0.5 NPK&bioN-P) treatments were better than the full NPK treatments in the second season. Soil microbial activity increased over time as a result of frequent bio-fertilizers application. This improved nutrient cycle efficiency during the second season. In both seasons, CK and NPK consistently performed worse than the integrated treatment. Bio-fertilizers increase productivity more than mineral fertilizers alone do. El-Desuki *et al.* (2006) and Das *et al.* (2007) reported that the bio-fertilizers use improves vegetative growth. Hafez & Geries (2018) and Padhan *et al.* (2024) reported that a 100% recommended fertilizer dose with phosphorus-solubilizing bacteria increased onion dry matter yield and fresh weight compared to the recommended fertilizer dose alone.

Table 1. The effect of mineral and biological fertilization on the vegetative characteristics (Length and diameter) of green onion plants

Treatment	Plant Length (cm)	Leaves Number	Root length (cm)	Stem Diameter (cm)	Leaves Diameter (cm)	Leaves Length (cm)
First Season						
CK	33.17^{d}	3.58^{bc}	12.98^{de}	0.6^{f}	0.4^{e}	23.26^{f}
NPK	43^{b}	4.67^{ab}	12.52^{de}	0.92^{de}	0.8^{c}	27.96^{de}
bioN	38^{c}	2.33^{c}	13.01^{d}	0.85^{e}	0.53^{d}	26.42^{e}
bioP	33.5^{d}	3.33^{bc}	15.68^{c}	0.98^{d}	0.55^{d}	22.5^{f}
bioN-P	35.67^{cd}	3.67^{bc}	10.95^{f}	0.88^{e}	0.52^{d}	26.23^{e}
NPK&bioN	43.05^{b}	4.33^{ab}	11.54^{ef}	1.13^{c}	0.9^{b}	30.17^{cd}
NPK&bioP	44^{b}	4^{abc}	11.57^{def}	1.17^{c}	0.85^{bc}	31.13^{bc}
NPK&bioN-P	48.7^{a}	5.67^{a}	15.84^{c}	1.44^{a}	1.03^{a}	33.08^{b}
0.5NPK&bioN-P	45.58^{ab}	4.33^{ab}	19.38^{a}	1.31^{b}	0.82^{bc}	35.33^{a}
0.75NPK&bioN-P	43^{b}	5.67^{a}	17.8^{b}	1.32^{b}	0.78^{c}	30.17^{cd}
Second Season						
CK	37.68^{d}	2.92^{c}	13.28^{d}	0.64^{d}	0.42^{f}	22.97^{d}
NPK	37.1^{de}	4.67^{ab}	12.14^{de}	0.83^{c}	0.58^{d}	28.99^{b}
bioN	35.92^{e}	4^{bc}	13.47^{d}	0.68^{d}	0.47^{ef}	24.83^{cd}
bioP	32.67^{f}	4^{bc}	15.63^{c}	0.95^{c}	0.62^{d}	22.5^{d}
bioN-P	40.17^{c}	4^{bc}	10.86^{e}	0.92^{c}	0.55^{de}	26.23^{c}
NPK&bioN	39.75^{c}	4.33^{abc}	11.39^{e}	1.13^{b}	0.82^{b}	29^{b}
NPK&bioP	40.66^{c}	4^{bc}	11.59^{e}	1.13^{b}	0.72^{c}	29.8^{b}
NPK&bioN-P	43.68^{b}	5.67^{a}	16.28^{c}	1.45^{a}	0.98^{a}	32.9^{a}
0.5NPK&bioN-P	47.42^{a}	5^{ab}	19.32^{a}	1.32^{a}	0.82^{b}	35.33^{a}
0.75NPK&bioN-P	40.75^{c}	5.33^{ab}	17.83^{b}	1.33^{a}	0.77^{bc}	30.12^{b}

Table 2. The effect of mineral and biological fertilization on the vegetative characteristics (Fresh and Dry weight) of green onion plants

Treatment	Fresh Weight (g)	Fresh Leaves Weight (g)	Fresh Steam Weight (g)	Fresh Root Weight (g)	Dry Root Weight (g)	Dry Leaves Weight (g)	Dry Steam Weight (g)
First Season							
CK	15.13^{cd}	1.53^{f}	5.77^{h}	1.62^{f}	0.29^{g}	0.69^{g}	8.43^{ab}
NPK	19.08^{bcd}	8.65^{d}	13.46^{g}	2.43^{e}	0.55^{ef}	2.49^{b}	6.36^{de}
bioN	12.75^{d}	5.95^{e}	23.39^{f}	2.45^{e}	0.58^{e}	0.99^{f}	5.3^{e}
bioP	23.29^{abc}	8.37^{de}	36.79^{b}	6.23^{a}	1.98^{a}	1.1^{ef}	8.89^{a}
bioN-P	19.91^{bcd}	9.19^{d}	33^{c}	3.55^{d}	0.84^{d}	1.27^{e}	7.99^{abc}
NPK&bioN	27.46^{ab}	21.59^{c}	33.89^{bc}	1.71^{f}	0.43^{f}	1.84^{d}	6.84^{cd}
NPK&bioP	20.51^{bcd}	19.48^{c}	28.54^{e}	3.6^{d}	1^{c}	1.97^{cd}	6.82^{cd}
NPK&bioN-P	33.03^{a}	31.92^{a}	51.64^{a}	5.25^{b}	1.24^{b}	3.04^{a}	8.97^{a}
0.5NPK&bioN-P	32.49^{a}	27.16^{b}	32.56^{cd}	4.43^{c}	0.67^{e}	2.11^{c}	7.28^{bcd}
0.75NPK&bioN-P	24.06^{abc}	24.99^{b}	29.29^{de}	4.9^{b}	0.82^{d}	2.08^{c}	6.5^{de}
Second Season							
CK	15.47^{ef}	1.64^{g}	6.72^{g}	1.62^{f}	0.29^{h}	0.69^{g}	8.43^{ab}
NPK	20.04^{cde}	8.92^{e}	10.99^{f}	2.47^{e}	0.54^{fg}	2.49^{b}	6.84^{cd}
bioN	14.28^{f}	5.08^{f}	23.42^{e}	2.41^{e}	0.58^{ef}	0.99^{f}	7.99^{abc}
bioP	21.34^{bcd}	7.74^{e}	36.83^{b}	6.23^{a}	1.98^{a}	1.1^{ef}	5.3^{e}
bioN-P	17.51^{def}	9.13^{e}	32.56^{cd}	3.55^{d}	0.84^{d}	1.27^{e}	7.28^{bcd}
NPK&bioN	23.14^{bc}	21.57^{d}	33.8^{bc}	1.72^{f}	0.43^{g}	1.84^{d}	6.5^{de}
NPK&bioP	18.6^{cdef}	20.81^{d}	29.52^{d}	3.6^{d}	1^{c}	1.97^{cd}	6.36^{de}
NPK&bioN-P	26.08^{b}	32.96^{a}	51.68^{a}	5.25^{b}	1.24^{b}	3.04^{a}	6.82^{cd}
0.5NPK&bioN-P	32.23^{a}	29.16^{b}	31.17^{cd}	4.43^{c}	0.67^{e}	2.11^{c}	8.97^{a}
0.75NPK&bioN-P	23.28^{bc}	26.54^{c}	29.55^{d}	4.9^{b}	0.82^{d}	2.08^{c}	8.89^{a}

Enhanced N and P contents drove biomass accumulation, supporting the high biomass in the (NPK&bioN-P) treatment. In a 2018–2019 field study in India, 75% NPK with N bio-fertilizers increased onion fresh weight by 10–12 % and dry weight by 8–10% compared to 100% NPK. N bio-fertilizers improve nutrient efficiency, aligning with the (0.75NPK&bioN-P) treatment performance (Tinna *et al.*, 2020). NPK (75%) with bio-fertilizers increased onion fresh weight by 12–15% and dry weight by 10–12% compared with 100% NPK. Enhanced N and P contents supports biomass, similar to integrated treatments (Kandil *et al.*, 2011).

The effect of mineral and biological fertilization on the plant chlorophyll content (SPAD) Values of green onion plants

Fig (1) illustrates the effect of minerals and bio-fertilizers on the SPAD of green onions. In both seasons, NPK produced the highest SPAD values, indicating a high N availability. The following closely followed integrated treatments demonstrated that the combination treatments may sustain healthy levels of chlorophyll. BioN, bioP, and bioN-P displayed low-to-moderate SPAD values, indicating restricted N or P availability. This confirms that bio-fertilizers are most effective when combined with mineral nutrients, particularly in low-fertility soils such as loamy sand. Phosphate-solubilizing microorganisms enhanced root colonization over time may have contributed to the +3.2% increase in the (NPK&bioP) treatment during the second season. The (NPK&bioN-P) remained constant without changing the amount of chlorophyll, the (0.75NPK&bioN-P) stayed constant, suggesting the possibility of reducing mineral fertilizer. Most of the integrated treatments outperformed the control and bio-only treatments in the second season, although they had somewhat lower SPAD values. The SPAD value of CK increased by +3%, most likely as a result of natural nutrient cycling or the remaining impacts from the previous season. Bio-fertilizers enhance N content, increase chlorophyll content, and increase N (3.18%) in the (NPK&bioN-P) treatment (Hafez and Geries, 2018). Padhan *et al.* (2024) reported an 8%–12% increase in onion leaf SPAD values compared to NPK alone. Enhanced N and P contents supported chlorophyll synthesis, supporting the inferred high SPAD values for NPK&bioN-P treatment. NPK (75%) with N bio-fertilizers increased onion leaf SPAD values by 10–14% compared to 100% NPK. N bio-fertilizers improved N

availability and enhanced chlorophyll content, consistent with 0.75NPK&bioN-P treatments (Tinna *et al.*, 2020). Kandil *et al.* (2011) showed that 75% NPK with bio-fertilizer increased onion leaf SPAD values by 12–15% compared to 100% NPK. Similar to NPK and bioN treatments, bio-fertilizers enhanced N content, supporting chlorophyll synthesis, related to the NPK&bioN treatment. Mohamed *et al.* (2023) illustrated that 75% NPK&bioN-P increased onion leaf SPAD values by 10–13% compared to 100% NPK. Integrated nutrient management improved N and P contents and enhanced chlorophyll content, aligning with the 0.75NPK&bioN-P treatments.

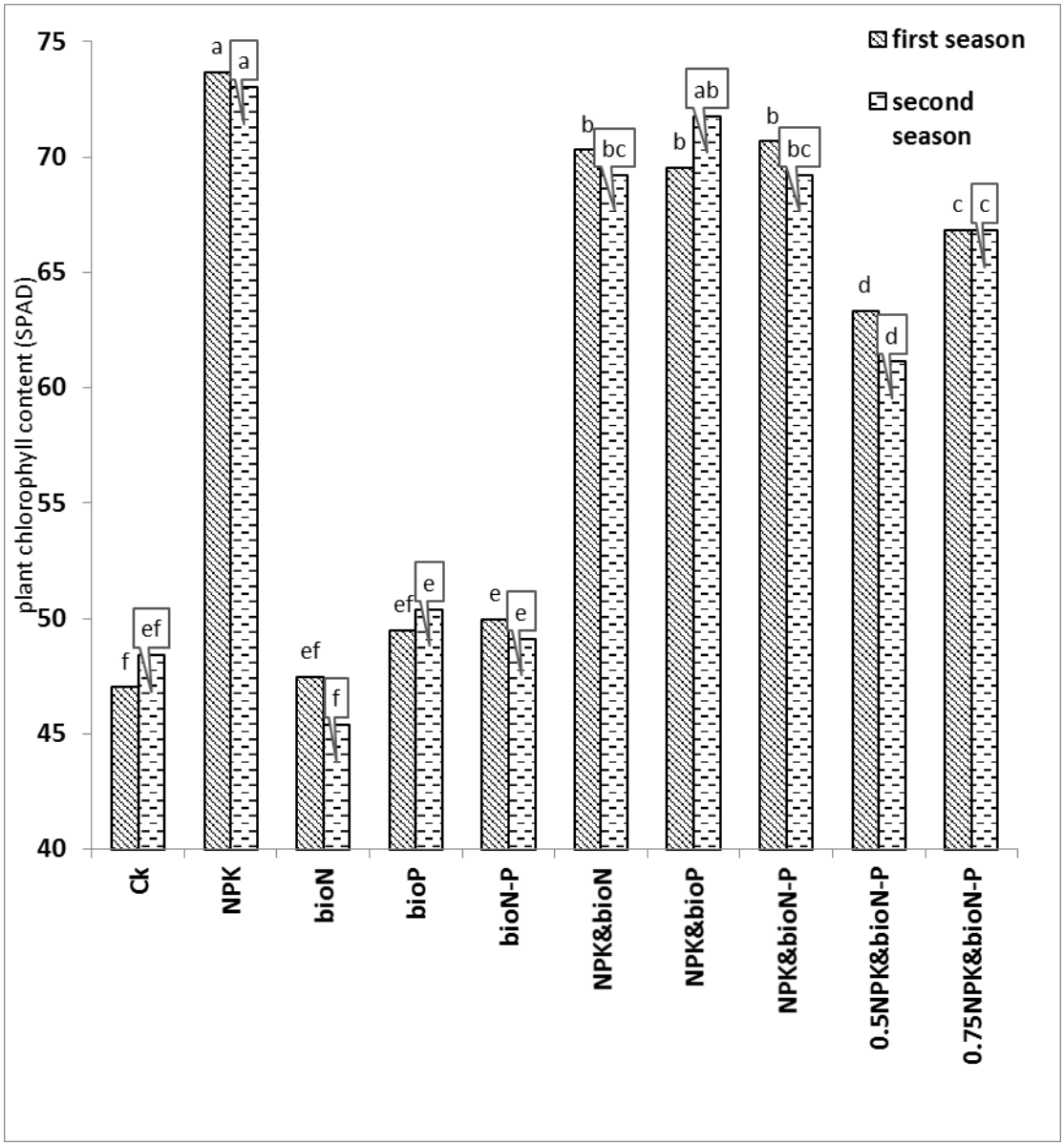

Fig 1. The effect of mineral and biological fertilization on plant chlorophyll content (SPAD) of green onion plants

The effect of mineral and biological fertilization on Plant N, P and K

Table (3) shows the effects of mineral and biological fertilization on N, P, and K plant. The NPK and bioN-P treatments had the highest plant N content (3.17%), significantly exceeding the others. NPK alone (2.72%) and NPK&bioN (2.75%) displayed high N levels. The CK treatment had the lowest N content (1.78%). The N content of partial NPK with bio-fertilizers (0.5NPK&bioN-P, 0.75NPK&bioN-P) was intermediate (2.22–2.62%), while the N content of bio-fertilizer-only treatments (bioN, bioP, and bioN-P) was lower (1.90–2.15%). The CK and bioN treatments had the highest P content (0.12%), followed by the bioP and bioN-P (0.09%) treatments. The P content was lower in all NPK treatments (0.07–0.08%), indicating that NPK administration may reduce P accumulation in plants compared to bio-fertilizers alone. The treatments with the highest K content (3.43%) were NPK&bioN-P, followed by NPK&bioN (2.85%), and 0.75NPK&bioN-P (2.83%). The lowest K levels were found in the control (2.18%) and bio-fertilizer-only treatments (1.82 –2.22%). For N and K absorption, the integrated treatment (NPK&bioN-P) was the most effective. The effect of Phosphorene without NPK may have contributed to the higher P content. Although they were less successful than full NPK with bio-fertilizers, partial NPK reductions (0.5NPK&bioN-P, 0.75NPK&bioN-P) however enhanced nutrient content.

In the second season, the highest plant N was observed for NPK&bioN-P (3.18%), which performed noticeably better than the other treatments. The CK was (1.79%), then bioN (1.95%), and finally bioP (1.97%). Although NPK&bioP (2.65%) and bioN-P (2.27%) were moderate, 0.5NPK&bioN-P (2.33%) were lower, and NPK (2.86%), NPK&bioN (2.87%), and 0.75NPK&bioN-P (2.89%) demonstrated high N content. The combined NPK&bioN-P treatments increased N content, most likely as a result of the complementary effects of bio-fertilizers (Phosphorene and Nitrobeine) and mineral fertilizers. BioN (0.12%) and CK (0.13%) had the highest P contents, suggesting significant P buildup in the absence of mineral fertilizers. 0.75NPK&bioN-P (0.07%) was the lowest. Additional treatments included NPK, NPK&bioP, and NPK&bioN-P (0.08%), bioP and bioN-P (0.09%), and NPK&bioN and 0.5NPK&bioN-P (0.08%). NPK-based treatments decreased P accumulation, whereas bio-fertilizer-only treatments increased P content, most likely because of the Phosphorene. Highest potassium (K%): NPK and bioN-P (3.43%), much greater than the others. BioP (1.82%) and bioN (1.85%) were the lowest. Other treatments include NPK and bioN (2.85%), bioN-P (2.22%), CK (2.18%), 0.75NPK and bioN-P (2.83%), NPK and bioP (2.55%), 0.5NPK and bioN-P (2.67%), and NPK (2.4%). K absorption was greatly increased by the combination of NPK and biofertilizers, with NPK and bioN-P being the most successful.

Integrated treatments (75–100% NPK + bio-fertilizers) increased onion plant N by 10–20%, as shown by Kandil *et al.* (2011) and Hafez & Geries (2018). Similar to Nitrobeine, N bio-fertilizers enhanced N fixation in the present study. Synergies between mineral K and bio-fertilizers enhanced K content. N and P bio-fertilizers increase P in onions by 10–18%, as shown by Mohamed *et al.* (2023) and Padhan *et al.* (2024). NPK often reduces P content owing to fixation, which is consistent with the findings of this study. NPK with bio-fertilizers increases onion plant K by 8–15%, as shown by Kandil *et al.* (2011) and Tinna *et al.* (2020). Bio-fertilizers alone often limit K content because of the low soil K mobilization.

Table 3. The effect of mineral and biological fertilization on Plant N, P and K

Treatment	First Season			Second Season		
	plant N (%)	plant P (%)	plant K (%)	plant N (%)	plant P (%)	plant K (%)
CK	1.78^{e}	0.12^{a}	2.18^{e}	1.79^{e}	0.13^{a}	2.18^{e}
NPK	2.72^{b}	0.08^{bc}	2.4^{d}	2.86^{b}	0.08^{bc}	2.4^{d}
bioN	1.90^{de}	0.12^{a}	1.85^{f}	1.95^{e}	0.12^{a}	1.85^{f}
bioP	1.95^{de}	0.09^{b}	1.82^{f}	1.97^{e}	0.09^{b}	1.82^{f}
bioN-P	2.15^{de}	0.09^{b}	2.22^{e}	2.27^{d}	0.09^{b}	2.22^{e}
NPK&bioN	2.75^{b}	0.08^{bc}	2.85^{b}	2.87^{b}	0.08^{cd}	2.85^{b}
NPK&bioP	2.6^{bc}	0.08^{bc}	2.55^{c}	2.65^{c}	0.08^{bc}	2.55^{c}
NPK&bioN-P	3.17^{a}	0.08^{bc}	3.43^{a}	3.18^{a}	0.08^{bc}	3.43^{a}
0.5NPK&bioN-P	2.22^{cd}	0.08^{bc}	2.67^{c}	2.33^{d}	0.08^{cd}	2.67^{c}
0.75NPK&bioN-P	2.62^{b}	0.07^{c}	2.83^{b}	2.89^{b}	0.07^{d}	2.83^{b}

Available Soil N, P, and K

Following green onion production under different fertilizer applications during the first (2022–2023) and second (2023–2024) seasons, the data supplied describe the soil available N, P, and K (ppm) in **Table (4)**. Available soil N during the first season, NPK&bioP (77.8 ppm) comes after NPK&bioN (84.0 ppm). CK showed the lowest level (16.6 ppm). NPK, in combination with bio-fertilizers, particularly Nitrobeine, significantly increased soil N relative to the initial 31.5 ppm. Limited N fixation without mineral fertilizers was indicated by the reduction of soil N. For the soil P, NPK&bioP (9.9 ppm) and NPK&bioN (9.4 ppm) were the next highest, followed by 0.5NPK&bioN-P (10.3 ppm). BioP (8.1 ppm) was lowest after CK, and bioN (7.95 ppm). All treatments raised soil P above 7.5 ppm, but 0.5NPK&bioN-P were the most successful because of Phosphorene. CK and bioN showed the least increase, indicating that P mobilization was limited in the absence of the combination treatments. For K in soil, NPK&bioP (108.73 ppm) was the highest, followed by NPK (100.3 ppm). NPK&bioN-P (63.02 ppm) and 0.75NPK&bioN-P (62.6 ppm) are the next lowest; followed by bioP (54.7 ppm). All treatments raised the soil K above 47.2 ppm. The largest increase was observed in NPK-based treatments. K levels were lower in the treatments that used only bio-fertilizers, indicating that there was less K mobilization in the absence of mineral fertilizers.

For N, NPK&bioN (84.0 ppm) were the highest, followed by NPK&bioP (77.87 ppm).
CK showed the lowest level (16.62 ppm). This pattern was similar to that observed in the first season. In the NPK-based treatments, soil N remained above the starting levels, whereas in the CK, bioN, and bioP treatments decreased. The highest P levels were found in NPK&bioN-P (11.05 ppm), NPK&bioN (10.15 ppm), and NPK&bioP (10.1 ppm). CK and bioN had the lowest (8.02 ppm), followed by bioP (8.6 ppm). NPK&bioN-P were more successful in the second season, but all treatments increased soil P over the initial 7.5 ppm. For K, NPK&bioN-P had the highest levels (119.25 ppm), followed by NPK (112.4 ppm). The CK (65.03 ppm) was the lowest after bioP (61.6 ppm). Gnanasundari *et al.* (2022) found that 75% NPK with bio-fertilizers increased soil N by 15–20%, similar to NPK, bioN-P, NPK, and bioP. Chen *et al.* (2021) reported a 10–15% increase in soil N, supporting the bio-fertilizers role in enhancing N fixation. Sulzbacher *et al.* (2018) noted a 10–15% N increase, aligned with the modest N boost of bioN-P. Bindraban *et al.* (2020) confirmed that phosphate-solubilizing bacteria increase soil P by 15–25%, matching bioP and bioN-P results. Ma *et al.* (2023) reported a 15–20% increase in P, supporting the high P of the (NPK&bioN-P) treatment in the second season. Eckhardt *et al.* (2018) noted that bio-fertilizers enhanced P availability by 15–20%, consistent with bioP. Gnanasundari *et al.* (2022) found that 75% NPK with bio-fertilizers increased soil K by 12–15%, similar to NPK&bioN-P and 0.5NPK& bioN-P. Ma *et al.* (2023) reported a 10–14% increase in K with integrated fertilization, aligning with NPK and bioN-P. Chen *et al.* (2021) noted that crop residue and mineral K enhanced soil K, supporting the need for mineral K input.

Table 4. The effect of mineral and biological fertilization on available soil N, P and K

Treatment	First Season			Second Season		
	soil N (ppm)	soil P (ppm)	soil K (ppm)	soil N (ppm)	soil P (ppm)	soil K (ppm)
CK	16.6^{f}	7.95^{c}	59.8^{b}	16.62^{f}	8.02^{e}	65.03^{bc}
NPK	34.1^{d}	9.0^{abc}	100.3^{a}	34.12^{d}	9.5^{bc}	112.4^{a}
bioN	22.2^{ef}	7.95^{c}	62.3^{b}	22.22^{ef}	8.02^{e}	69.6^{bc}
bioP	21.7^{ef}	8.1^{c}	54.7^{b}	21.75^{ef}	8.6^{de}	61.6^{c}
bioN-P	25.9^{e}	8.35^{bc}	67.71^{b}	25.9^{e}	8.52^{e}	73.5^{bc}
NPK&bioN	84.0^{a}	9.4^{abc}	67.3^{b}	84.0^{a}	10.15^{b}	78.04^{b}
NPK&bioP	77.8^{b}	9.9^{ab}	108.73^{a}	77.87^{b}	10.1^{bc}	65.03^{bc}
NPK&bioN-P	26.9^{e}	9.2^{abc}	63.02^{b}	26.95^{e}	11.05^{a}	119.25^{a}
0.5NPK&bioN-P	47.2^{c}	10.3^{a}	67.4^{b}	47.25^{c}	9.55^{bc}	75.8^{b}
0.75NPK&bioN-P	50.7^{c}	8.75^{abc}	62.6^{b}	50.75^{c}	9.32^{cd}	67.2^{bc}

CONCLUSION

The study (2022-2023 and 2023-2024 seasons) demonstrated that integrated nutrient management combining NPK mineral and bio-fertilizers (Nitrobeine, Phosphorene) significantly enhanced green onion (*Allium fistulosum* L.) growth, nutrient content, and soil fertility in loamy sand soil. The NPK&bioN-P treatments consistently maximized fresh weight (33.03 g), dry stem (8.97 g), plant N (3.18%), K (3.43%), soil N (26.95 ppm), P (11.05 ppm), and K (119.25 ppm), and indicating superior plant vigor and soil health. The 0.5NPK&bioN-P treatments achieved similar biomass (32.23 g fresh weight) and continued root/leaf growth, highlighting the potential to reduce mineral fertilizer use by 50%. Bio-fertilizers-only treatments (bioN, bioP, and bioN-P) improved soil P (6.93, 14.67 and 13.60% Consecutively), but were limited by low N and K, emphasizing the need for mineral supplementation in low-organic-matter soils. These findings support the adoption of integrated fertilization strategies to sustainably enhance Egypt's onion production and reduce environmental and cost challenges.

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الملخص العربي

تأثير الأسمدة المعدنية والحيوية المتكاملة على نمو البصل (*Allium fistulosum*) وحالة العناصر الغذائية في التربة

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يُعدّ البصل (*Allium cepa* L.) محصولًا اقتصاديًا مهمًا في مصر، يحتاج إلى إدارة متكاملة للتغذية لتحسين الإنتاجية والحفاظ على خصوبة التربة، خاصةً في الأراضي ذات المادة العضوية المنخفضة. أُجريت هذه الدراسة في جامعة دمنهور بمزرعة التجارب بكلية الزراعة، خلال موسمي الزراعة ٢٠٢٢–٢٠٢٣ و٢٠٢٣–٢٠٢٤ لتقييم تأثير مزيج من الأسمدة المعدنية والأسمدة الحيوية (نيتروبين وفوسفورين) على خصوبة التربة ونمو ومحتوى العناصر الغذائية لنبات البصل الأخضر (*Allium fistulosum* L.) المزروع في تربة رملية طينية. تم تصميم التجربة باستخدام تصميم عشوائي كامل بثلاثة مكررات. تضمنت المعاملات: الكنترول (CK)، التسميد المعدنى (NPK)، السماد الحيوى النيتروجينى – نتروبين – (bioN)، السماد الحيوى الفوسفورى – فوسفورين – (bioP)، الأسمدة الحيوية معا (bioP&bioN)، التسميد المعدنى مع النتروبين (bioN&NPK)، التسميد المعدنى مع الفوسفورين (NPK&bioP)، المعاملة المتكاملة – تسميد معدنى مع الأسمدة الحيوية – (NPK bioN-P) – نصف الأسمدة المعدنية مع الأسمدة الحيوى (0.5NPK+bioN-P) – ثلاثة أرباع الأسمدة المعدنية مع الأسمدة الحيوية (0.75NPK+bioN-P). تم قياس الصفات النباتية، ومحتوى النبات من العناصر الغذائية، وعناصر التربة، ومحتوى الكلوروفيل (SPAD). أظهرت المعاملة (NPK&bioN-P) تحسنًا ملحوظًا في الوزن الطازج (٣٣,٠٣ جرام)، والوزن الجاف للساق (٨,٩٧ جرام)، ومحتوى النبات من النيتروجين (٣,١٨%) والبوتاسيوم (٣,٤٣%)، وكذلك مستويات العناصر في التربة: النيتروجين (٢٦,٩٥ جزء فى المليون)، الفوسفور (١١,٠٥ جزء فى المليون)، البوتاسيوم (١١٩,٢٥ جزء فى المليون). كما حصلت معاملة (0.5NPK+bioN-P) على نتائج مشابهة من حيث الوزن الطازج (٣٢,٢٣ جرام) ونمو الجذور والأوراق، مما يدل على إمكانية تقليل الأسمدة الكيميائية بنسبة ٥٠% عند استخدام الأسمدة الحيوية دون التأثير السلبي على المحصول. بالإضافة إلى ذلك، زادت معاملات الأسمدة الحيوية فقط (bioN-P – bioP– bioN) من محتوى التربة من الفوسفور (٦,٩٣ و ١٤,٦٧ و ١٣,٦٠% على التوالي). تُظهر هذه الدراسة أن الإدارة المتكاملة للتغذية، وخاصة باستخدام الأسمدة الكيميائية الكاملة أو المخففة مع نيتروبين وفوسفورين (NPK&bioN-P and 0.5NPK&bioN-P)، توفر استراتيجية مستدامة لزيادة إنتاجية البصل الأخضر مع الحفاظ على صحة التربة. تُعد هذه النتائج ذات صلة كبيرة بزيادة إنتاجية البصل في مصر التي تسعى إلى تقليل استخدام الأسمدة الكيميائية وتبني ممارسات زراعية صديقة للبيئة.

الكلمات الدالة: البصل الأخضر، الأسمدة الحيوية، الأسمدة المعدنية، العناصر الكبرى، نيتروبين، فوسفورين.