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## Response of Potato (*Solanum Tuberosum* L.) and Green Bean (*Phaseolus Vulgaris* L.) Crops to Mycorrhizal, NPK and Sheep Manure Fertilization in Soil

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**Abstract:** A field experiment was conducted in the Al-Qubba region, north of Mosul, to evaluate the effects of mycorrhizal inoculation, NPK compound fertilization, and sheep manure on the growth parameters and yield components of potato and green bean. The study was carried out in a calcareous Silty Clay soil characterized by low organic matter content and a deficiency in plant-available nitrogen and phosphorus. The experiment followed a Randomized Complete Block Design (RCBD) with three replicates, comprising 18 experimental units resulting from the interaction of the studied factors. The results indicated that all treatments significantly enhanced the growth of both crops, leading to marked increases in growth indicators (plant height, shoot dry weight, and number of branches). Furthermore, there was a significant improvement in yield components: tuber weight, number of tubers, and yield per plant for the potato crop; and number of pods per plant, number of seeds per pod, and total yield for the green bean crop. Additionally, nitrogen and phosphorus concentrations in potato tubers and green bean pods were increased. The integrated treatment (Mycorrhiza + NPK) significantly outperformed all other treatments across all vegetative growth parameters, yield components, and nutrient concentrations (N and P) for both crops.

**Keywords:** Potato, Green bean, Fertilization

### Introduction

Arbuscular mycorrhizal fungi (AMF) play a pivotal role in enhancing plant growth and productivity through a non-pathogenic symbiotic relationship established under natural conditions between the fungus and the host plant. Over 90% of vascular plants are capable of forming these symbiotic associations, which persist throughout the plant's life cycle (Sweeney et al., 2022). This symbiosis represents a key mechanism for improving plant health and yield by augmenting the uptake of essential nutrients, such as nitrogen (N), calcium (Ca), and magnesium (Mg), and particularly immobile soil elements like phosphorus (P). These fungi efficiently transport nutrients from soil zones beyond the reach of the root system; the mycorrhizal hyphae extend from the roots, effectively acting as an expanded root system that increases the reach, depth, and rate of water and nutrient absorption. Furthermore, fungal hyphae serve as a biological reservoir for nutrients, accumulating phosphorus within their structures and supplying it to the plant during periods of low soil P-availability (Smith et al., 2011; Ezawa & Saito, 2018). Mycorrhizae also play a crucial role in mitigating drought and salinity stress

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by enhancing water uptake, boosting antioxidant activities, and regulating phytohormones such as auxins and cytokinins (Kakouridis et al., 2022; Wang et al., 2023). Beyond abiotic stress, mycorrhizae bolster plant resistance against diseases and pests by stimulating the production of inhibitory compounds, including lignin and flavonoids, as well as phosphatase enzymes known for their antimicrobial and anti-insect activities (Weng et al., 2022; Li et al., 2024; Chen et al., 2024; Farhaoui et al., 2025). Additionally, mycorrhizae contribute to the improvement of soil physical properties by promoting the formation of stable soil aggregates and increasing soil organic matter content (Rillig & Mummey, 2006; Fall et al., 2022; Wu et al., 2024)

Carrara et al. (2023) highlighted that soil inoculation with Arbuscular Mycorrhizal Fungi (AMF) resulted in an increase in tuber yield by up to 23% and a boost in antioxidant activity by as much as 120%. Furthermore, it led to a nine-fold increase in ergothioneine concentration and a 46% rise in soluble sugar levels. In a related context, Rodiño et al. (2025) indicated that AMF inoculation effectively enhances bean growth and improves grain quality. Their study suggests that the strategic integration of symbiotic mycorrhizae can mitigate pesticide dependence and foster the development of healthier, more sustainable food systems .

High crop productivity can be achieved through the balanced application of NPK fertilizers tailored to the specific requirements of the crop. This approach not only optimizes fertilizer costs but also mitigates adverse environmental impacts. Hochmuth and Hanlon (2014) reported that applying appropriate rates of NPK enhances the growth of potato crops and significantly increases both tuber number and total yield. Similarly, it has been observed that NPK fertilization in common beans (*Phaseolus vulgaris*) leads to marked increases in plant height and leaf number. Furthermore, it substantially improves yield components, including pod length, the number of pods per plant, and the number of seeds per pod .

Sheep manure is a nutrient-rich organic fertilizer renowned for its capacity to enhance the physical, chemical, and biological properties of soil. Its application reduces bulk density, increases water-holding capacity, promotes the stability of soil aggregates, and elevates soil organic matter content. Furthermore, it fosters microbial diversity and activity while supplying essential nutrients to the soil (Rayne & Aula, 2020; Elouear et al., 2016; Yu et al., 2024). Previous studies have demonstrated that fertilizing potatoes with sheep manure leads to significant increases in plant height, stem number, and chlorophyll content, as well as an improvement in tuber number and weight (El-Mesairy et al., 2022; Ierna & Distefano, 2024; Hou et al., 2024). Similarly, it has been found that sheep manure application enhances leaf area, leaf number, plant height, pod number and weight, and total yield in green beans (Bucagu et al., 2017; Sharifi et al., 2024).

The integration of chemical fertilizers with bio-fertilizers or organic amendments often yields greater benefits than their sole application. Alhrout et al. (2016) observed that the highest green bean yield was achieved by combining poultry manure with NPK fertilizer. Moreover, Tadang et al. (2025) reported that the maximum yield for beans resulted from the co-application of cattle manure and vermicompost alongside NPK. Similarly, the inoculation of potatoes with mycorrhizal fungi at a rate of 15 g plant<sup>-1</sup>, in the presence of mineral fertilizer, played a vital role in increasing production (Carong & Rafiuddin, 2025).

Given the scarcity of research investigating the combined effects of bio-, mineral, and organic fertilizers on the growth and yield of potato and green bean, this study was conducted. The objective was to evaluate the impact of mycorrhizal inoculation, both in the presence and absence of NPK and sheep manure, on the growth parameters and yield components of these two crops. This research aims to contribute to ongoing efforts to enhance the productivity of these essential crops.

## Method

A field experiment was conducted in the Al-Qubba region, Nineveh Governorate, during the 2018 growing season. The study was carried out on a Silty Clay soil;

Table 1. Illustrates the geographic coordinates of the experimental site and the taxonomic classification of the study soil

| Location | Geographic Coordinates      | Order    | Suborder | Great Group    |
|----------|-----------------------------|----------|----------|----------------|
|          | GPS                         | Entisols | Fluvents | Typic Fluvents |
| Al-Qubba | °36.51'00"N,<br>°43.25'00"E |          |          |                |

Soil samples were collected from a depth of 0–30 cm from various locations across the experimental field. The collected samples were thoroughly mixed and homogenized, then passed through a 2-mm mesh sieve. From this mixture, a composite sample was obtained for the determination of key physical, chemical, and biological properties. Table (2) illustrates the physical and chemical characteristics of the study soil, which were analyzed following the methodologies described by Rikani et al. (2023).

Table 2. Some chemical and physical properties of Study Soil

| Property                               | Unit                     | Value      |
|----------------------------------------|--------------------------|------------|
| pH                                     | –                        | 7.7        |
| Electrical Conductivity (EC)           | dS m <sup>-1</sup>       | 0.75       |
| Available Potassium (K)                |                          | 160        |
| Available Phosphorus (P)               |                          | 9.2        |
| Available Nitrogen (N)                 | mg kg <sup>-1</sup>      | 15.8       |
| Calcium Carbonate (CaCO <sub>3</sub> ) | g kg <sup>-1</sup>       | 284        |
| Organic Matter                         |                          | 11.2       |
| Cation Exchange Capacity (CEC)         | cmol(+) kg <sup>-1</sup> | 28.5       |
| Field Capacity                         | g kg <sup>-1</sup>       | 300        |
| Bulk Density                           | Mg m <sup>-3</sup>       | 1.34       |
| Sand                                   |                          | 95         |
| Silt                                   | g kg <sup>-1</sup>       | 425        |
| Clay                                   |                          | 480        |
| Soil Texture                           | –                        | Silty Clay |

Experimental area was then divided into two separate fields, one for each crop. Each field was organized into three blocks, with each block consisting of six experimental units. Each unit contained three ridges, with a ridge length of 3 m and an inter-ridge spacing of 75 cm. The experiment included six treatments for each crop: a control treatment, mycorrhizal inoculation, NPK fertilization (18:18:18) following the recommended rates of 110 kg dunam<sup>-1</sup> for potato (Al-Nuaimi, 1999) and 100 kg dunam<sup>-1</sup> for green bean (Al-Abidi, 2010), a combination of Mycorrhiza + NPK, sheep manure application at a rate of 50 t ha<sup>-1</sup>, and a combination of sheep manure + mycorrhizal inoculation

The mycorrhizal inoculum was harvested from a field previously cultivated with onion after the harvest stage. The infection of the plants with mycorrhizal fungi was verified via microscopic examination according to the method described by Phillips and Hayman (1970). Subsequently, fungal spores were isolated using the wet-sieving and decanting method as described by Gerdemann and Nicolson (1963). The spore density in the field soil was estimated at an average of 50 spores per 10 g of soil, which is consistent with the findings of Hammadi et al. (2017) regarding mycorrhizal spore isolation.

The two crops were planted on ( / / ). Potato tubers (American 'Laberda' cultivar) were planted at a rate of one tuber per hill at a depth of 10–12 cm, with an intra-row spacing of 25 cm. Green bean seeds (cv. 'Izkyrda') were sown at a rate of 3 seeds per hill. Sufficient spacing was maintained between experimental units to prevent nutrient leaching and cross-contamination between treatments. Thirty days after planting, the potato and bean fields were inoculated with soil containing mycorrhizal inoculum, followed immediately by irrigation.

The experiment was concluded on ( / / ). Plant samples were then ground and digested using concentrated sulfuric acid (H<sub>2</sub>SO<sub>4</sub>) and 30% hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>). The concentrations of nitrogen (N) and phosphorus (P) in the acid extract were determined following the procedures of Tandon (1999). Finally, the total content of each element was calculated by multiplying the concentration by the dry weight (Jones, 2001).

## Results and Discussion

### Fertility Evaluation of the Study Soil

As indicated in Table (2), the available phosphorus (P) concentration in the study soil was 9.2 mg kg<sup>-1</sup>, which falls below the critical threshold of 10–15 mg kg<sup>-1</sup> proposed by Sandaña et al. (2018). This deficiency in available P may be attributed to the high calcium carbonate content (284 g kg<sup>-1</sup>), elevated soil pH (7.7), and low organic matter content (11.2 g kg<sup>-1</sup>) (Table 2). These conditions subject phosphorus to retention and precipitation reactions, thereby reducing its bioavailability. The dissociation of calcium carbonate into  $\text{Ca}^{2+}$  and  $\text{CO}_3^{2-}$  raises the soil solution pH, facilitating the reaction of dissolved calcium ions with

monocalcium phosphate to form dicalcium or tricalcium phosphate precipitates of lower solubility. Over time, these compounds transform into insoluble octacalcium phosphate. Furthermore, the high clay content in the study soil ( $480 \text{ g kg}^{-1}$ ) increases the specific surface area, enhancing the contact between dissolved phosphorus and clay minerals, which leads to greater P-fixation and reduced availability (Xiong et al., 2022).

Similarly, Table (2) shows a low concentration of available nitrogen (N) in the research soil ( $15.8 \text{ mg kg}^{-1}$ ), which is below the critical level of  $20 \text{ mg kg}^{-1}$  suggested by Al-Mosuli et al. (2019). The low N-availability is likely due to the low soil organic matter content ( $11.2 \text{ g kg}^{-1}$ ), nitrate leaching, and reduced microbial activity resulting from high temperatures, drought, lack of vegetative cover, and poor residue management (Hudhaifa, 2025). Moreover, the high calcium carbonate levels and alkaline pH promote nitrogen loss through ammonia volatilization (Li et al., 2022; Ahmad et al., 2023). Consequently, the study soil requires an effective fertilization program to enhance nutrient availability, ensure optimal plant growth, and maximize yield. Overall, these findings align with previous studies emphasizing that calcareous soils necessitate precise fertilization management (Khan et al., 2018; Ali et al., 2020).

### **Mycorrhizal Colonization Percentage of Potato and Green Bean Plants**

As presented in Table (3), the average mycorrhizal colonization rate of the roots reached 30% for both potato and green bean crops one month after planting. The table also indicates that the colonization percentages after two months were 40% and 60% for the two crops, respectively. This variation in colonization rates is consistent with the findings reported by Al-Kartani et al. (2013).

Table 3. Mycorrhizal root colonization percentage in potato and green bean plants

| Plant type | Mycorrhizal colonization percentage |                  |
|------------|-------------------------------------|------------------|
|            | After a month                       | After two months |
| Potato     |                                     |                  |
| Beans      | 30                                  | 40               |
|            | 30                                  | 60               |

### **The Effect of Mycorrhizal Inoculation, NPK Fertilizer, and Sheep Manure on Some Growth Parameters and Yield Components of Potato and Bean Crops**

Results presented in Table (4) indicate that all fertilization treatments and their interactions led to significant improvements in growth, resulting in increased values of growth parameters for both potato and green bean crops. The highest growth values for both crops were recorded in the Mycorrhiza + NPK treatment. The interaction between mycorrhizal inoculation and NPK mineral fertilization led to a significant increase in plant height, shoot dry weight, and the number of branches per plant, with increase percentages of 46.60%, 71.89%, and 116.98%, respectively, for the potato crop. For green beans, the increase rates for the same three parameters were 58.06%, 12.96%, and 36.92%, respectively, compared to the control treatment, which recorded the lowest values for all indicators in both crops. Furthermore, Table (5) demonstrates that the applied fertilization treatments had a distinct impact on yield components, causing significant increases in these traits. The highest yield component values for both crops were observed in the Mycorrhiza + NPK treatment. Soil inoculation with mycorrhiza combined with NPK mineral fertilization resulted in a significant increase in the number and weight of potato tubers and total yield, with increase percentages of 114.50%, 117.46%, and 344.11%, respectively, compared to the control. In green beans, the increase rates for the number of pods per plant, number of seeds per pod, and yield per plant were 77.41%, 39.63%, and 100%, respectively, compared to the control.

The observed increases in growth parameters and yield components under mycorrhizal inoculation and NPK fertilization may be attributed to the vital role of mycorrhizal fungi in enhancing plant growth. These fungi coat the roots with hyphae that functions as an extended root system, thereby increasing root expansion and penetration. This enhances the volume and rate of water and nutrient absorption. Additionally, mycorrhizae possess the ability to regulate growth hormones, particularly auxins and cytokinins. Moreover, the increase in organic matter in mycorrhiza-inoculated soil improves the physical, chemical, and biological properties of the soil, which is positively reflected in growth and yield components.

The improvement in plant growth and yield components can also be attributed to the role of NPK compound fertilizer in providing essential elements (N, P, and K). These elements influence cell division and elongation; Nitrogen (N) is fundamental in the synthesis of chlorophyll, proteins, enzymes, and nucleic acids (Ye et al., 2022). Phosphorus (P) is essential for the formation of energy compounds (ATP) and the synthesis of

Tryptophan, a precursor for the auxin Indole-acetic acid (IAA), as well as its role in DNA and RNA structures (Khan et al., 2023). Potassium (K) acts as a cofactor in cell growth and division, plays a key role in regulating cellular osmotic pressure, and contributes to stomatal opening and closing (Xu et al., 2020).

The increase in growth and yield for both potato and bean crops may further be attributed to the enhancement of physical, fertile, and biological soil properties resulting from the addition of sheep manure. This organic amendment is rich in nutrients and crucial for boosting microbial activity and soil organic content (Du et al., 2020). These findings are in agreement with Al-Tawarah et al. (2025) and Oladele et al. (2024), who reported improvements in potato and bean growth following mycorrhizal inoculation and sheep manure fertilization.

Table 4. The effect of mycorrhizal inoculation, NPK fertilizer, and sheep manure on some growth parameters of potato and bean crops

| Treatment                 | Potato<br>Tuber Weight<br>(gm tuber-1) | Potato<br>Tuber Number<br>(Tuber plant-1) | Potato<br>Yield<br>(g plant-1) | Green beans<br>Number of<br>pods<br>(pod plant-1) | Green beans<br>Number of<br>seeds<br>(Seed pod- 1) | Green beans<br>Yield<br>(g plant-1) |
|---------------------------|----------------------------------------|-------------------------------------------|--------------------------------|---------------------------------------------------|----------------------------------------------------|-------------------------------------|
| Control                   | f38.60                                 | e6.30                                     | f243.18                        | e8.90                                             | d13.32                                             | f200                                |
| Mycorrhiza                | e69.10                                 | d6.50                                     | e656.45                        | d10.20                                            | c14.33                                             | e220                                |
| NPK                       | c77.20                                 | b11.00                                    | c849.20                        | b11.63                                            | b15.21                                             | c250                                |
| Mycorrhiza+ NPK           | a82.80                                 | a13.70                                    | a1080                          | a15.79                                            | a18.60                                             | a400                                |
| Sheep manure              | b80.01                                 | c8.11                                     | d753.33                        | c10.89                                            | f9.14                                              | d230                                |
| Sheep manure + Mycorrhiza | d76.40                                 | b10.93                                    | b883.12                        | 10.87c                                            | 13.79e                                             | 210f                                |

#### The Effect of Mycorrhizal Inoculation, NPK Fertilizer, and Sheep Manure on Nitrogen and Phosphorus Concentrations (%) in Potato Tubers and Bean Pods

Figures (1) and (2) illustrate that all applied fertilization treatments and their interactions led to an increase in nitrogen (N) and phosphorus (P) concentrations in both potato tubers and bean pods. As shown in Figure (1), the interaction treatments (Mycorrhiza + NPK and Mycorrhiza + Sheep Manure) outperformed all other treatments regarding N and P concentrations in potato tubers. The nitrogen concentration reached 2.10%, representing an increase of 35.48% compared to the control treatment, which recorded the lowest value (1.55%). Furthermore, the figure indicates that the highest phosphorus concentration in tubers was 0.39% under mycorrhizal inoculation, an increase of 77.27% over the control, which registered the lowest P concentration at 0.22%.

Figure (2) shows that the highest concentrations of N and P in bean pods were observed in the Mycorrhiza + NPK treatment, reaching 3.21% and 0.41%, respectively. These values represent increase percentages of 73.51% and 70.83%, respectively, compared to the control for each element.

Table 5. The Effect of mycorrhizal inoculation, NPK fertilizer, and sheep manure on some yield components of potato and bean crop

| Treatment          | Potato<br>Plant<br>Height<br>(cm) | Potato<br>Dry<br>weight.<br>(gm) | Potato<br>Nu.branches<br>Plant-1 | Green beans<br>Plant Height<br>(cm) | Green beans<br>Dry<br>weight<br>(gm) | Green beans<br>Nu.branches<br>Plant-1 |
|--------------------|-----------------------------------|----------------------------------|----------------------------------|-------------------------------------|--------------------------------------|---------------------------------------|
| Control            | f58.40                            | f39.10                           | f6.30                            | c54.30                              | f12.40                               | g6.50                                 |
| Mycorrhiza         | d62.10                            | d53.11                           | e9.00                            | a75.40                              | d13.60                               | c8.21                                 |
| NPK                | b69.50                            | c58.63                           | b12.00                           | b64.50                              | b14.20                               | d7.75                                 |
| Mycorrhiza+ NPK    | a85.62                            | a67.21                           | a13.67                           | a85.83                              | a15.62                               | a8.90                                 |
| Sheep manure       | e60.31                            | e43.33                           | d10.31                           | c56.12                              | e12.81                               | f6.97                                 |
| Sheep manure +Myc. | c70.12                            | b60.42                           | c10.92                           | b67.45                              | 13.78c                               | 7.53e                                 |

The low concentrations of N and P in potato tubers and bean pods in the unfertilized (control) soil may be attributed to the low availability of these elements in the soil (Table 2), as N and P are subject to various loss processes that reduce their bioavailability. Conversely, the increased concentration of these elements in tubers and pods upon mycorrhizal inoculation can be attributed to the role of these fungi in enhancing nutrient uptake. Mycorrhizae support root absorption through an extensive network of fungal hyphae. Additionally, sheep manure plays a vital role in supplying the plant with N and P, while simultaneously improving the physical and biological soil properties that facilitate nutrient absorption. These findings are consistent with those of Nielsen et al. (1998), Ingraffia et al. (2019), Yang et al. (2020), and Karavidas et al. (2022), who observed significant

increases in N and P concentrations in plants following mycorrhizal inoculation and fertilization with sheep manure.

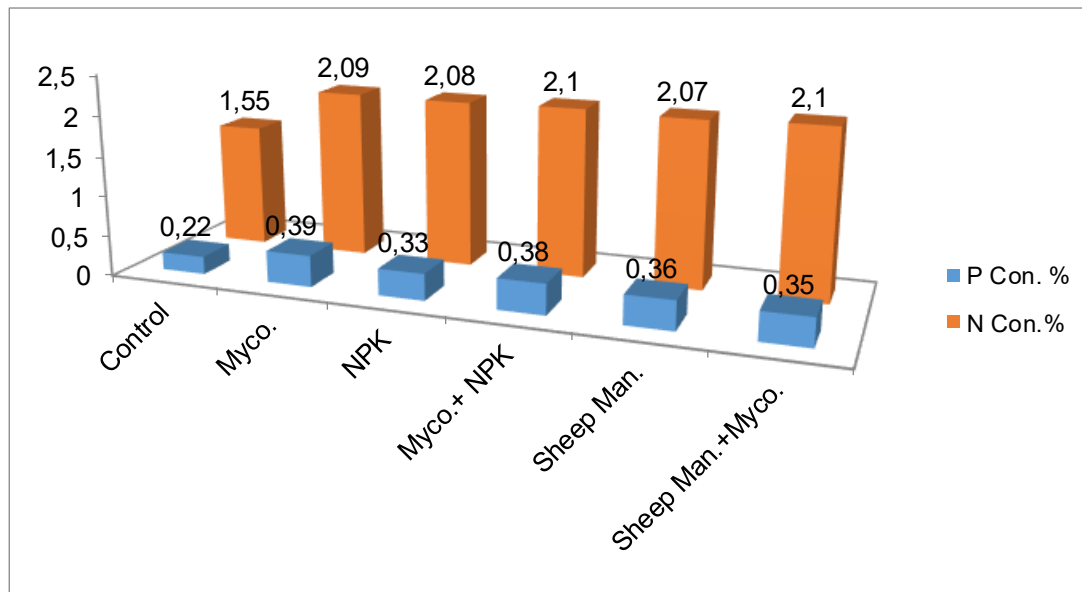


Figure 1. The effect of mycorrhizal inoculation, NPK fertilizer, and sheep manure on nitrogen and phosphorus concentrations (%) in potato tubers

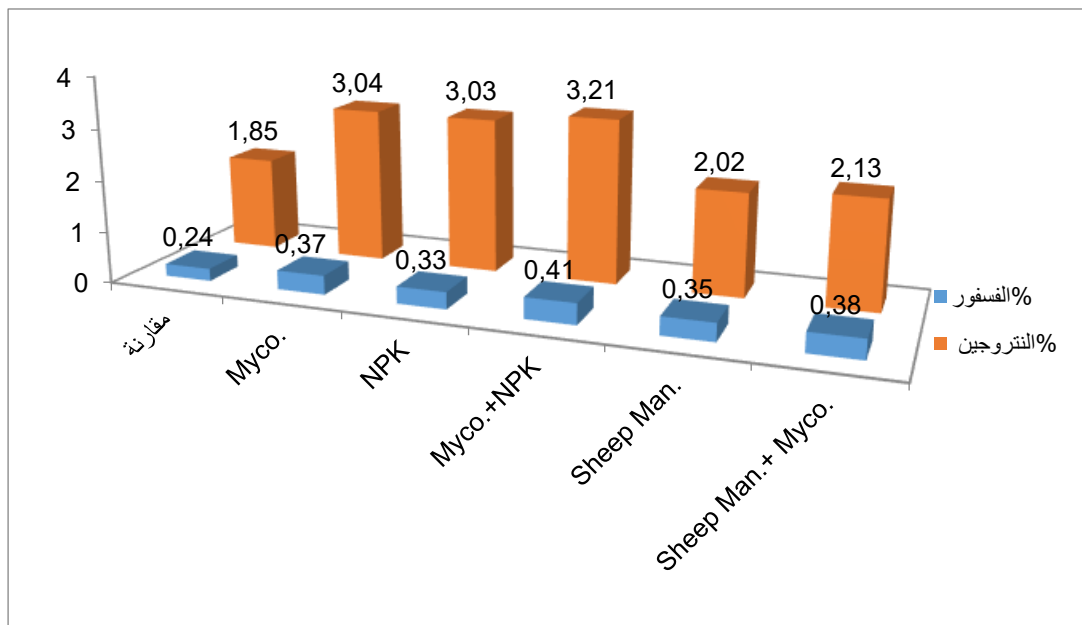


Figure 2. The effect of mycorrhizal inoculation, NPK fertilizer, and sheep manure on nitrogen and phosphorus concentrations (%) in green bean pods

## Conclusions

Based on the aforementioned results, it can be concluded that the soil in this study suffers from a significant deficiency in available nitrogen (N) and phosphorus (P). Soil inoculation with mycorrhizal fungi, combined with the application of NPK mineral fertilizer and sheep manure (organic amendment), substantially improved vegetative growth and enhanced the total yield of both potato and green bean crops. Furthermore, these treatments led to a marked increase in N and P concentrations within the plant tissues. Among all evaluated treatments, the Mycorrhiza + NPK interaction consistently demonstrated superior performance, achieving the highest values across all growth parameters, yield components, and nutrient concentrations for both crops.

## Scientific Ethics Declaration

\* The authors declare that the scientific, ethical, and legal responsibility for this article published in EPSTEM Journal belongs to the authors.

## Conflict of Interest

\* The authors declare that they have no conflicts of interest

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