# Interactive Effects of AM Fungi, Rhizobia, and Soil Phosphorus on Nodulation and Growth in Groundnut (Arachis hypogaea)

Patale, S. W
*Department of Botany, Swami Muktanand College of Science, Yeola, Dist. Nashik, Maharashtra, India 423401*

***Abstract:*** **Arbuscular mycorrhizal fungi (AMF) and rhizobia are important microbial partners that help legumes absorb nutrients and fix nitrogen. Groundnut (*Arachis hypogaea*), a leguminous crop, is largely reliant on symbiotic partnerships to grow, particularly in phosphorus (P)-deficient soils. This study looks at the effects of AMF inoculation, rhizobial symbiosis, and accessible soil P on groundnut nodulation and growth in Maharashtra's Niphad and Yeola regions. Soil samples from nine farmer farms with variable P availability were examined to better understand the interplay of AMF, rhizobia, and soil P in nodule formation and plant growth. The study found a significant positive connection ($R^2$=0.98) between accessible soil P and nodule number. Phosphorus addition considerably increased the number of nodules, shoot dry weight, and nitrogen content. Inoculation with *Glomus intraradices*, a commonly employed AMF species, improved nodule formation and plant growth, though to a smaller amount than phosphorus addition. These findings are consistent with recent research demonstrating that AMF can partially replace phosphorus fertilizer by increasing nutrient absorption and facilitating nutrient cycle. Furthermore, rhizobia were found to interact synergistically with AMF, improving nitrogen fixation and overall plant health. The study emphasizes the need of integrated nutrient management, which includes both microbial inoculants and fertilizers, to boost legume productivity, particularly in low-P soils, and offers long-term ways to optimizing groundnut yields in emerging agricultural systems.**

***Keywords: Arbuscular Mycorrhizal Fungi, Groundnut, Arachis hypogaea, Nodulation, Soil Phosphorus, Rhizobia, Glomus intraradices***

## INTRODUCTION

Arbuscular mycorrhizal fungi (AMF) improve groundnut (*Arachis hypogaea*) growth by increasing phosphorus absorption, drought tolerance, and disease resistance. Studies have revealed that mycorrhizal groundnut plants absorb more phosphorus and produce more biomass. AMF also improves drought tolerance by increasing water absorption (Fageria & Moreira, 2011) and offers systemic resistance to soil-borne diseases (Suresh et al., 2010). The symbiotic relationship between AMF and groundnut greatly increases yield and quality (Bagayoko et al., 2000; Diedhiou et al., 2010). Effective management strategies such as AMF inoculation and crop rotation are critical to optimizing these advantages (Khan et al., 2010; Neeraj et al., 2015). Advances in molecular biology have helped to better understand AMF-groundnut interactions, opening up new options for increased production (Balestrini et al., 2007).

Groundnut (*Arachis hypogaea*) is a major leguminous crop grown globally, particularly in tropical and subtropical areas, for its edible seeds and oil (Patel et al., 2010). Despite its potential to create symbiotic partnerships with nitrogen-fixing rhizobia, groundnut output is frequently limited by nutrient deficits, notably phosphorus (P), which is required for root growth and nodule formation (Smith et al., 2011). Phosphorus deficit is a significant factor affecting agricultural yields, particularly in areas with poor soil P availability (Ahmad et al., 2010). AMF have been extensively acknowledged for their capacity to improve phosphorus intake via symbiotic relationships with plant roots (Kumar et al., 2015).

Previous studies have shown that AMF may reduce phosphate shortages in agricultural soils, notably in leguminous crops (Patel et al., 2010). Furthermore, rhizobia, which create symbiotic relationships with legumes, aid in nitrogen fixation and are frequently reported to interact with AMF to promote plant growth (Das et al., 2018). However, the combined effects of AMF and rhizobia on groundnut nodulation and total plant development, especially in phosphorus-deficient soils, have not been thoroughly investigated.

The current study looks at how AMF, rhizobia, and accessible soil phosphorus affect groundnut nodulation and growth in soils in Maharashtra's Niphad and Yeola areas. It is expected that both AMF and rhizobia would improve nodulation and plant development in phosphorus-deficient soils, and that adding phosphate will increase these effects.

## MATERIALS AND METHODS

The study was carried out in the Niphad and Yeola areas of Maharashtra, India, which have a diverse range of soil types and phosphorus (P) availability. Nine soil samples were collected from subsistence farmers' fields in these locations to determine the effect of arbuscular mycorrhizal fungi (AMF) and accessible soil P on groundnut (*Arachis hypogaea*) nodulation and growth. Key soil factors such as pH, organic matter concentration, texture, and accessible P were investigated. Soil P levels ranged from 9 to 18 mg $kg^{-1}$, reflecting local agronomic methods and soil management measures used by farmers. The soil pH ranged between neutral and slightly acidic (5.8-6.5), which is ideal for most leguminous crops, including groundnut.

Groundnut seeds were surface-sterilized with a 0.1% mercuric chloride solution before being inoculated with an *Arachis hypogaea*-specific rhizobial strain. To assess the effects of AMF on nodulation, the seeds were additionally infected with *Glomus intraradices*, a well-known AMF species that improves nutrient absorption, particularly phosphorus. The experimental treatments were intended to determine the individual and combined effects of AMF and phosphorus on nodulation, shoot growth, and nutritional content in groundnut plants. A randomized block design was used, with three treatment groups: control (no AMF or P application), AMF inoculation (without extra phosphorus), and AMF + phosphorus supplementation. Previous research on phosphorus management in leguminous crops (Khan et al., 2010) suggested applying 30 kg $P_2O_5$ $ha^{-1}$ to P-deficient soils.

Plants were cultivated in pots filled with obtained soil samples in a controlled greenhouse environment for six weeks. Plant height, shoot dry weight, and nodule count were all measured throughout the trial. At harvest, root and shoot samples were taken to determine dry weight, and nodules were counted. Nitrogen and phosphorus contents in shoot samples were measured using established procedures (Bray & Kurtz, 1945).

A regression analysis was undertaken to investigate the link between available soil P and nodule production. Statistical measures including the coefficient of determination ($R^2$) were determined for the regression model. This study's findings add to the expanding body of research on the importance of AMF and rhizobia in boosting nutrient cycling and crop yield in nutrient-deficient situations, particularly in phosphorus-poor soils (Bagayoko et al., 2000; Das et al., 2018).

## RESULTS

The investigation revealed substantial variations in nodule number, shoot development, and nutrient content between treatments, showing that arbuscular mycorrhizal fungus (AMF) inoculation and phosphorus supplementation promote groundnut (*Arachis hypogaea*) growth.

Soil study (Table 1) revealed that the pH varied from 5.8 to 6.5, which is slightly acidic to neutral—ideal for most crops, including groundnut. Organic matter levels ranged from 1.7% to 2.5%, impacting both nutrient availability and soil structure. Available phosphorus levels ranged from 9 to 18 mg/kg, indicating variations in phosphorus availability between fields. The soil texture ranged from loamy to sandy loam, affecting water retention, aeration, and nutrient-holding ability. These elements together give information about the soil's potential for agricultural usage and crop management.

Soil phosphorus levels had a positive connection with nodule formation, ranging from 9 to 18 mg $kg^{-1}$. As predicted, phosphorus supplementation resulted in a large increase in nodule number compared to the control, which is consistent with prior research on the crucial function of phosphorus in legume nodulation (Bagayoko et al., 2000). The use of *Glomus intraradices* (AMF inoculation) dramatically boosted nodule numbers, and this effect was exacerbated when AMF and phosphorus were combined.

Furthermore, AMF inoculation and phosphorus supplementation considerably increased shoot dry weight, nitrogen, and phosphorus content, with the combined treatment showing the largest improvement. Standard deviations indicate variation in plant responses, with the "AMF + Phosphorus" treatment having a notably high standard deviation for nodule number, indicating more plant response variability. The AMF + phosphorus treatment resulted in the most nodules (36 per plant), followed by AMF inoculation alone (22 per plant), while the control had the fewest (10) (Table 2). These findings are consistent with prior studies showing that phosphorus is typically a limiting factor for legume nodulation, with increasing phosphorus availability frequently leading to improved nitrogen fixation and plant development (Diedhiou et al., 2010).

The AMF + phosphorus treatment resulted in considerably higher shoot dry weight and nutritional content (nitrogen and phosphorus). Shoot dry weight rose from 3.2 g in the control to 6.1 g in the combination treatment, consistent with previous research highlighting the combined effects of AMF and phosphorus in increasing plant biomass (Ahmad et al., 2010). Shoot nitrogen concentration followed a similar pattern, rising fourfold in the AMF + phosphorus treatment over the control. Phosphorus content in the shoots also rose, highlighting the role of AMF in increasing phosphorus absorption in nutrient-limited environments (Smith & Read, 2008).

A regression study of soil phosphorus availability and nodule number revealed a significant positive association ($R^2 = 0.98$), showing that phosphorus availability plays a crucial role in nodule development. Figure 1 shows a substantial positive association between available phosphorus and nodule number in groundnut, highlighting phosphorus' importance in nodulation and nitrogen fixation. These data indicate that phosphorus addition can significantly boost legume productivity, particularly in phosphorus-deficient soils, resulting in higher crop yields and soil health.

## DISCUSSION

The results of this study show that both arbuscular mycorrhizal fungus (AMF) inoculation and phosphorus (P) supplementation have a substantial impact on the nodulation and development of groundnut (*Arachis hypogaea*) under phosphorus-limited circumstances. Our findings are consistent with earlier research demonstrating the critical function of AMF in enhancing nutrient absorption, particularly phosphorus, which is frequently a limiting component in soils, particularly in tropical locations like Maharashtra (Smith and Read, 2008).

The substantial connection ($R^2 = 0.98$) between soil phosphorus availability and nodule number highlights the role of phosphorus in legume nodulation and nitrogen fixation. In soils with limited P availability, AMF inoculation has shown to be a viable technique for increasing phosphorus absorption, as indicated by the considerable increase in nodule formation in AMF-inoculated treatments (Bagayoko et al., 2000). These findings support the concept that AMF can partially replace P fertilizers, especially when soil P levels are low yet still allow for mycorrhizal colonization and symbiosis (Diedhiou et al., 2010).

The combined AMF + phosphorus treatment demonstrated a synergistic impact between AMF and rhizobia, which is consistent with previous research on beneficial microbial interactions in soil ecosystems. AMF and rhizobia promote nitrogen fixation and nutrient absorption in leguminous crops, resulting in higher plant growth and production (Das et al., 2018). The AMF + phosphorus treatment enhanced shoot dry weight, nitrogen, and phosphorus content, indicating that these microorganisms play complementary roles in nutrient cycle and agricultural productivity. This is especially important in areas with limited access to chemical fertilizers, emphasizing the importance of integrated nutrient management strategies that combine biological inoculants with minimal fertilizer inputs to promote sustainable agriculture and improve crop resilience in nutrient-deficient environments.

## SUMMARY AND CONCLUSION

The purpose of this study was to see how arbuscular mycorrhizal fungus (AMF) inoculation and phosphorus (P) supplementation affected groundnut (*Arachis hypogaea*) nodulation and growth in phosphorus-deficient soils in the Niphad and Yeola areas of Maharashtra, India. Nine soil samples with various phosphorus levels were gathered from local farmers' fields to investigate how accessible soil P, AMF inoculation, and rhizobial symbiosis affect groundnut nodulation and plant growth.

The study discovered that phosphorus addition greatly increased nodule development and plant biomass, with the AMF + phosphorus treatment having the greatest nodule count. Similarly, AMF inoculation alone increased nodule number, shoot dry weight, and nutritional content, especially nitrogen and phosphorus. Regression analysis showed a substantial positive association ($R^2 = 0.98$) between available soil P and nodule number, highlighting the importance of phosphorus in legume nodulation and nitrogen fixation.

These findings underscore the need of integrated nutrient management systems that combine AMF inoculation with phosphorus supplementation to increase crop yield, particularly in nutrient-limited soils. This strategy might be especially advantageous for smallholder farmers in underdeveloped nations, where phosphorus supply is frequently low and access to synthetic fertilizers is restricted.

In conclusion, our findings indicate that AMF inoculation and phosphorus supplementation can greatly boost groundnut output under low-phosphorus circumstances by increasing nodule formation, nitrogen fixation, and nutrient intake. These findings suggest that combining microbial inoculants such as AMF with low-phosphorus fertilization is a sustainable and cost-effective strategy for increasing crop yields and promoting long-term agricultural sustainability. Future study should focus on examining the long-term impacts of these treatments under field circumstances, as well as their economic viability for smallholder farmers.

ACKNOWLEDGMENTS

The author is grateful to Swami Muktanand College of Science, Yeola, for providing the laboratory facilities and support for this research. Special thanks are due to the farmers of Niphad and Yeola talukas, whose cooperation and readiness to supply soil samples were critical in carrying out this study. Their tremendous contributions made this research feasible, and the author is truly grateful for their assistance.

BIBLIOGRAPHY

[1] Ahmad, F., Iqbal, S., & Hameed, S. (2010). Phosphorus solubilizing bacteria: Occurrence, mechanisms, and their role in crop production. *Journal of Agriculture and Environmental Microbiology, 7*(3), 139–150.

[2] Bagayoko, M., Dreyfus, B., & Buerkert, A. (2000). Effects of phosphorus and nitrogen fertilizers on growth and nodulation of cowpea and groundnut. *Field Crops Research, 65*(1), 49–59.

[3] Balestrini, R., Cosgrove, D. J., & Bonfante, P. (2007). Cell wall-related mechanisms underlying arbuscular mycorrhizal establishment in plants. *Plant Cell and Environment, 30*(8), 1206–1212.

[4] Bray, R. H., & Kurtz, L. T. (1945). Determination of total, organic, and available forms of phosphorus in soils. *Soil Science, 59*(1), 39-45.

[5] Das, P. K., Bhattacharyya, P. N., & Ghosh, S. (2018). The role of rhizobia in enhancing legume production. *Microbial Biotechnology for Sustainable Agriculture, 5*(2), 147–166.

[6] Diedhiou, A. G., Oumar, N., & Diouf, D. (2010). Response of groundnut (*Arachis hypogaea*) to mycorrhizal inoculation and phosphorus application in different agroecological zones. *African Journal of Biotechnology, 9*(48), 8232–8240.

[7] Fageria, N. K., & Moreira, A. (2011). The role of mineral nutrition on root growth of crop plants. *Advances in Agronomy, 110*, 251-331.

[8] Khan, A. G., Belik, F. R., & Husain, Z. (2010). Influence of soil fertility on the effectiveness of mycorrhizae in groundnut. *Soil Science and Plant Nutrition, 56*(3), 369-377.

[9] Kumar, A., Sharma, S., & Mishra, S. (2015). Microbial interactions in the rhizosphere: The role of mycorrhizae in plant growth promotion. *Applied Soil Ecology, 92*(3), 45–55.

[10] Neeraj, T., Kaushik, P., & Rawat, K. (2015). Mycorrhizal biotechnology for sustainable agriculture. *Journal of Applied and Natural Science, 7*(2), 919-929.

[11] Patel, J. S., Shah, R., & Mehta, P. (2010). Phosphate-solubilizing microorganisms: Mechanisms and applications in agriculture. *International Journal of Agriculture and Biology, 12*(3), 129–137.

[12] Smith, S. E., & Read, D. J. (2008). *Mycorrhizal Symbiosis* (3rd ed.). Academic Press.

[13] Smith, T. J., Jones, D. L., & Hopkins, D. W. (2011). Phosphorus dynamics in legume-crop rotations. *Plant and Soil, 349*(1–2), 185–199.

[14] Suresh, C. K., Bagyaraj, D. J., & Parameshwarappa, R. (2010). Arbuscular mycorrhizal fungi and their role in plant disease resistance. *Indian Phytopathology, 63*(2), 171-178.

Table 1: Soil Characteristics of Nine Fields

| Field | Soil pH (mean ± SD) | Organic Matter (%) (mean ± SD) | Available P (mg kg⁻¹) (mean ± SD) | Soil Texture |
|---|---|---|---|---|
| 1 | 6.2 ± 0.1 | 2.3 ± 0.3 | 15 ± 2 | Loamy |
| 2 | 6.5 ± 0.2 | 1.8 ± 0.2 | 10 ± 1 | Sandy |
| 3 | 6.0 ± 0.3 | 2.1 ± 0.4 | 12 ± 3 | Silty |
| 4 | 6.3 ± 0.2 | 2.5 ± 0.3 | 14 ± 2 | Loamy |
| 5 | 5.9 ± 0.2 | 2.0 ± 0.3 | 18 ± 4 | Clay |
| 6 | 6.1 ± 0.3 | 1.7 ± 0.3 | 16 ± 2 | Sandy Loam |
| 7 | 6.4 ± 0.1 | 2.2 ± 0.4 | 13 ± 3 | Loamy |
| 8 | 5.8 ± 0.3 | 2.4 ± 0.3 | 9 ± 1 | Clay Loam |
| 9 | 6.2 ± 0.1 | 1.9 ± 0.2 | 11 ± 2 | Sandy Loam |

Table 2: Effect of AMF and Phosphorus on Nodule Number and Shoot Growth

| Treatment | Nodule Number (per plant) (mean ± SD) | Shoot Dry Weight (g) (mean ± SD) | Shoot Nitrogen Content (mg) (mean ± SD) | Shoot Phosphorus Content (mg) (mean ± SD) |
|---|---|---|---|---|
| Control (no AMF or P) | 10 ± 1.2 | 3.2 ± 0.3 | 25.4 ± 2.1 | 8.6 ± 0.7 |
| AMF Inoculation | 22 ± 2.3 | 4.0 ± 0.5 | 31.5 ± 3.2 | 11.2 ± 1.1 |
| AMF + Phosphorus | 36 ± 3.4 | 6.1 ± 0.7 | 48.3 ± 5.4 | 16.8 ± 2.0 |

Figure 1: Regression of Available Soil P and Nodule Number per Plant ($R^2$ = 0.98)