

---

## Research Article

### Growth and yield of maize applicated by *Rizhobium spp.* from legume and non-legume rhizosphere

Tirto Wahyu Widodo\*, Ilham Muhklisin, Setyo Andi Nugroho, Rudi Wardana, Umi Safitri Alifia Ummah

Department of Agriculture Production, Politeknik Negeri Jember, Indonesia

---

#### Article history:

Submitted 18 July 2023

Accepted 28 October 2023

Published 5 December 2023

#### Keywords:

Direct mechanism

IAA synthesize

Phosphate solubilizer

Phytostimulator

Rhizobacteria

#### \*Corresponding author:

E-mail:

[tirtowahyuwidodo@polije.ac.id](mailto:tirtowahyuwidodo@polije.ac.id)

#### Abstract

*Rhizobium spp* can affect plant growth in non-legume crops directly by synthesis of phytostimulator and solubilization of inorganic phosphate. However, the ability of *Rhizobium spp* from legume and non-legume rhizosphere to trigger the growth of non-legume crops is different. This research aims to analyze the ability of *Rhizobium spp* isolates to produce IAA hormones and phosphate solvent and determine the response of maize with the application of *Rhizobium spp* from the legume and non-legume rhizosphere. This study was carried out in two stages, where the first stage at Bioscience Laboratory Politeknik Negeri Jember, while the second stage at Kaliurang field, Jember, Indonesia (altitude 146 m asl, temperature 21°C - 34°C, and soil type was inceptisol) from September 2022 to January 2023. The field experiment was arranged in a complete randomized design (crd) with the application of *Rhizobium spp* isolates from various rhizosphere as a treatment consisting of without *Rhizobium spp* (control), maize-rhizosphere isolate, rice-rhizosphere isolate, soybean-rhizosphere isolate, edamame-rhizosphere isolate, and peanut-rhizosphere isolate. Every treatment was replicated four times. The results showed that *Rhizobium spp* isolates from legume and non-legume rhizospheres can synthesize indole acetic acid and solubilize phosphate. This condition was indicated by the solubilized phosphate content in the planting medium, which was higher in the application of *Rhizobium spp* compared to the control. Inoculation of *Rhizobium spp* from several rhizospheres showed a significant effect on plant height, stem diameter, ear weight without husks, and ear dry weight compared to control. These bacteria are able to trigger the growth of maize through direct and indirect mechanisms. In addition, the plant height that was treated with maize-rhizosphere *Rhizobium spp* was better than rice. It is suspected that *Rhizobium spp* from the maize rhizosphere is more adaptable when applied to growing media for maize crops, so that it can increase plant height.

---

#### How to cite:

Widodo, T. W., Muhklisin, I., Nugroho, S. A., Wardana, R., Ummah, U. S. A. (2023). Growth and yield of maize applicated by *Rizhobium spp.* from legume and non-legume rhizosphere. *Journal of Agriculture and Applied Biology*, 4(2): 151 - 160. doi: 10.11594/jaab.04.02.05

## 1. Introduction

*Rhizobium spp.* is a type of bacteria that can offer nutrients to plants. These bacteria are capable of infecting and producing root nodules on plants in association with the Leguminosae family. Root nodules are the product of a symbiotic relationship between legume and *Rhizobium spp.*, which fixes nitrogen in the atmosphere and produces nitrogen nutrients for plants (Liu et al., 2018). In recent years, numerous studies have been investigating the use of *Rhizobium spp.* associated with non-legume crops, such as rice, maize, barley, sunflower, radishes, among others. According to the results of these studies, non-legume crops can interact with rhizobia and benefit from their plant growth promotion activities. However, much more research is required to analyze the potential benefits and drawbacks of such associations, as well as to focus on the development of rhizobial strains capable of increasing agricultural output under a variety of environmental conditions (Fahde et al., 2023).

In addition to being symbiotic with legume crops, *Rhizobium spp.* can form non-specific associative interactions with the roots of non-legume without producing true nodules on the root (Hussain et al., 2014). Under specific conditions, these bacteria operate as a phosphate solvent, produce hormones, and fix nitrogen in conjunction with non-legume crops (Afzal & Bano, 2008). *Rhizobium spp.* have a positive impact on the growth of non-legume, either directly or indirectly through several processes (Mehboob et al., 2009). The directly methods by increasing phytohormone and vitamin synthesize, increasing nutrient uptake by plants, increasing stress tolerance, organic phosphate mineralization, and inorganic phosphate solubilization.

*Rhizobium spp.* is a facultative symbiont that can live as a typical component of soil microflora in the absence of a host plant, but can also thrive freely as a heterotroph in the presence of host plant roots. These bacteria are free-living and motile in soil, where they get nutrition from the remains of deceased species. According to Yoneyama et al. (2017), *Rhizobium spp.* bacteria can be discovered in the rhizosphere of non-legume plants. *Rhizobium spp.* bacteria was found and isolated from rhizosphere of maize (Celador-Lera et al., 2017).

Furthermore, Mehboob et al., (2009) found several strains of *Rhizobium spp.* tested on maize had the ability to enhance root length, shoot length, and plant dry weight compared to a control treatment without *Rhizobium spp.* Because certain *Rhizobium spp.* bacteria are capable of producing hormones, they can stimulate plant growth in both legume and non-legume crops (Elhaisoufi et al., 2021). Previous study on the application of rhizobium isolates from legumes and non-legumes to food crops is not widely known, therefore, this experiment was conducted to determine the cultivation of maize using *Rhizobium spp.* from legume and non-legume rhizosphere. In recent years, research has shown that *Rhizobium spp.* can also associate with non-legume plants, ultimately leading to growth stimulation through direct and indirect mechanisms. A hypothesis is developed that *Rhizobium spp.* from legume and non-legume rhizosphere may have a positive impact on maize growth and yield.

## 2 Materials and methods

### 2.1 Research location

This study was carried out in second stages, where the first stage at Bioscience Laboratory Politeknik Negeri Jember, while the second stage at Kaliurang field, Jember, Indonesia from September 2022 to January 2023 (altitude of 146 m above sea level, temperature 21°C - 34°C, and soil type is incepstisol).

### 2.2 Experimental design and treatment

This research involves both laboratory and field. A variety of potential *Rhizobium spp.* isolates were investigated in the laboratory using qualitative and quantitative descriptive methods. The

field study implemented a non-factorial Completely Randomized Design (CRD) with six treatments, namely the application of *Rhizobium spp.* isolate at a concentration of  $1 \times 10^7$  cfu.ml<sup>-1</sup> to maize medium, with each treatment repeated four times. *Rhizobium spp.* treatment as follows:

A : without *Rhizobium spp.* (control)

B : 4.7 ml of maize-rhizosphere *Rhizobium spp.* (non legume crop, gramineae)

C : 11 ml of rice-rhizosphere *Rhizobium spp.* (non legume crop, gramineae)

D : 7.3 ml of soybean-rhizosphere *Rhizobium spp.* (legume crop)

E : 6.3 ml of edamame-rhizosphere *Rhizobium spp.* (legume crop)

F : 9.7 ml of peanuts-rhizosphere *Rhizobium spp.* (legume crop)

### 2.3 Selection of *Rhizobium spp.* isolates

Laboratory tests were used to select rhizobium isolates from legume and non-legume rhizospheres in order to get suitable isolates, including:

#### IAA (Indole Acetoc Acid) test

The IAA test, which involves inoculating bacterial isolates with loop needles and incubating them for 2-3 days in *Trypticase Soy Agar* (TSA) medium. Then 1 ml of Salkovsky reagent was put above the colony and incubated in a dark area, the color of the bacterial isolate changed to pink, indicating that it was positive for IAA ([Kachhap et al., 2015](#)).

#### Phosphate solubilizer test

Phosphate solubilizer test was performed by inoculating bacterial isolates into media pikovskaya and then incubating them for 7 days. The presence of a halo zone or clear zone around the bacterial colony indicates the ability of bacteria to dissolve phosphate ([Ventorino et al., 2014](#)).

### 2.4 Propagation of *Rhizobium spp.* isolates

Before the *Rhizobium* isolates were propagated, tools and materials were sterilized in an autoclave at 121 °C for 5 minutes. The initial culture was made by diluting 2-5 ose isolates up to 5 dilutions, with the last dilution series as a replacement medium. The alternative media produced from water and rice bran are stirred until homogeneous before the isolates are inoculated into them with a ratio of the initial and alternative media of 1:9, so that a liter is obtained for each isolate.

### 2.5 Crop management and *Rhizobium spp.* application

Field implementation begins with planting corn seeds into the planting medium in polybags. Embroidery, thinning, weeding, and watering are carried out periodically as needed. Application of *Rhizobium spp.* was performed twice, namely at 7 and 21 days after planting (dap), according to each treatment (a half dose per application). Fertilization was done twice at 14 and 42 dap using NPK Phonska and Urea according to standard doses. Harvesting is done when the maize is 95 days old.

### 2.6 Collecting data and statistical analysis

The data observed in this study consisted of: the ability of bacteria to synthesize IAA and dissolve phosphate; fresh stem weight; fresh leaf weight; ear weight without husk; ear dry weight; 100 seed weight; and soil phosphate content after planting. Laboratory data such as IAA and phosphate test results were analyzed qualitatively, while field observation data were tested using the orthogonal contrast.

### 3 Result and discussion

#### 3.1 *Rhizobium* spp. bacteria's ability to synthesize IAA

The ability of bacterial isolates to create IAA was tested using TSA medium. Isolates that turn pink suggest that they have the ability to create the IAA hormone. IAA test results for *Rhizobium* spp. can be seen in Table 1.

Table 1. *Rhizobium* spp. qualitative test for IAA production

| Origin of <i>Rhizobium</i> spp<br>Isolate | Isolate colour                                                                      |                                                                                      | Descriptions |
|-------------------------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|--------------|
|                                           | Before                                                                              | After                                                                                |              |
| Maize rhizosphere                         |    |    | Turns pink   |
| Rice rhizosphere                          |    |    | Turns pink   |
| Soybean rhizosphere                       |   |   | Turns pink   |
| Edamame rhizosphere                       |  |  | Turns pink   |
| Peanuts rhizosphere                       |  |  | Turns pink   |

According to laboratory studies, *Rhizobium* spp. can produce IAA and dissolve phosphate. Each bacterial isolate on the observation table can produce IAA, as indicated by the color change to pink after being treated with Salkovski's reagent and placed in the dark for 1 hour. After being exposed to Salkovski reagent, IAA-producing bacterial isolates turned pink (Gunasinghe & Edirisinghe, 2020). The results of this study are also similar to those published by Sudewi et al. (2020), who discovered that IAA-producing bacteria isolates changed color to pink after being given the Salkovski reagent.

#### 3.2 *Rhizobium* spp. bacteria's ability to solubilize phosphate

Bacterial isolates were tested for dissolving phosphate by inoculating them on Pikovskaya medium (Ventorino et al., 2014). The growth of the isolates was detected after 7 days of incubation. A halo zone (clear zone) will form surrounding the colony in media containing phosphate-solubilizing endophytic isolates.

Table 2. *Rhizobium spp.* qualitative test for solubilizing phosphate

| Origin of <i>Rhizobium spp.</i><br>Isolate | Isolate appearance                                                                  | Isolates ability to solubilize<br>phosphate |
|--------------------------------------------|-------------------------------------------------------------------------------------|---------------------------------------------|
| Maize rhizosphere                          |    | +                                           |
| Rice rhizosphere                           |    | +                                           |
| Soybean rhizosphere                        |    | +                                           |
| Edamame rhizosphere                        |    | +                                           |
| Peanuts rhizosphere                        |  | +                                           |

Note: + means *Rhizobium spp.* isolate has the ability to solubilize phosphate

Based on Table 2, all isolates can solubilize phosphate, as evidenced by the existence of a clear zone (*halo zone*) around the isolate. According to Pande et al. (2017), the ability to solubilize phosphate is characterized by the creation of a clear zone around the bacteria in the media, with a greater clear zone indicating a higher degree of phosphate dissolving concentration. Plants can't absorb phosphorus in its bound form; thus, it must be changed into a more soluble form before being made available to them. Insoluble and bonded phosphate can be converted by soil microbes like fungi and bacteria into a soluble form that plants can absorb (Elfianti et al., 2021).

### 3.3 Plant height

The treatment of *Rhizobium spp.* had a very significant effect compared to the control. In comparison between the gramineae, there was a significant difference between the *Rhizobium spp.* treatment from maize and rice rhizospheres, whereas the *Rhizobium spp.* treatment from maize rhizospheres had a higher average. The plant heights of maize are provided in Table 3 below.

Table 3. Plants heights of maize

| Treatment                            | Plant height (cm) |    |        | Notation |
|--------------------------------------|-------------------|----|--------|----------|
| Control vs All treatments            | 144.40            | vs | 150.09 | **       |
| Non-legume (B,C) vs Legume (D,E,F)   | 150.16            | vs | 150.04 | ns       |
| Maize vs Rice                        | 152.88            | vs | 147.44 | *        |
| Soybean, Edamame (D,E) vs Peanut (F) | 150.27            | vs | 149.58 | ns       |
| Soybean vs Edamame                   | 150.42            | vs | 150.11 | ns       |

Note: (\*\*) means a highly significant difference, and (ns) means a non-significant difference

Based on [Table 3](#), the *Rhizobium spp.* treatment had a highly significant difference in the plants height compared to the control, with an average of 150.09 cm. In comparison between the graminiae, there was a significant difference between the *Rhizobium spp.* treatment from maize and rice rhizospheres, whereas the *Rhizobium spp.* treatment from maize rhizospheres had a higher average of 152.88 cm. It is because of the ability of *Rhizobium spp.* to produce IAA hormone. According to the studies of [Rao et al. \(2018\)](#), IAA might have helped increase the plant's height. In particular, the bacteria's production of IAA increases the total root surface, leading to enhanced mineral uptake from the soil ([Amezquita et al., 2022](#)). This can affect the hormonal balance in plants and, as a result, influence their growth. According to [Qureshi et al. \(2013\)](#), the genus *Rhizobium* is an effective plant growth promoter in maize cultivars because of its ability to increase photosynthetic rate by up to 21%.

### 3.4 Stem diameters

The treatment of *Rhizobium spp.* from several rhizospheres exhibited a highly significant difference in stem diameters compared to the control treatment (based on orthogonal contrast). The stem diameter results are provided in [Table 4](#) below.

Table 4. Stem diameters of maize

| Treatment                            | Stem diameter (cm) |    |      | Notation |
|--------------------------------------|--------------------|----|------|----------|
| Control vs All treatments            | 2.02               | vs | 2.18 | **       |
| Non-legume (B,C) vs Legume (D,E,F)   | 2.21               | vs | 2.17 | ns       |
| Maize vs Rice                        | 2.27               | vs | 2.14 | ns       |
| Soybean, Edamame (D,E) vs Peanut (F) | 2.19               | vs | 2.14 | ns       |
| Soybean vs Edamame                   | 2.20               | vs | 2.17 | ns       |

Note: (\*\*) means a highly significant difference, and (ns) means a non-significant difference.

Based on [Table 4](#), the *Rhizobium spp.* treatment had a highly significant difference in the stem diameter compared to the control (2.18 cm). The maize rhizosphere of *Rhizobium spp.* generated the highest stem diameter (2.27 cm), while the control had the lowest (2.02 cm). Plant growth may be enhanced by the IAA from *Rhizobium spp.* According to [Fu et al. \(2015\)](#), IAA influences and induces the expansion and elongation of plant cells. This factor is critical in regulating the size of the maize stem. The IAA can trigger stem length growth and increase apical dominance, allowing plants to grow higher. Additionally, the IAA stimulates the production of new cell walls, increasing the amount of tissue in the stem and enlarging its diameter ([Orozko et al., 2023](#)).

### 3.5 Ear weight without husk

Based on the orthogonal contrast test results, the treatment of *Rhizobium spp.* From all rhizosphere exhibited a highly significant difference in cob weight without husks compared to the control treatment. The cob weight results without husks are provided in [Table 5](#).

Table 5. Ear weight without husks

| Treatment                            | Ear weight without husk (g) |    |        | Notation |
|--------------------------------------|-----------------------------|----|--------|----------|
| Control vs All treatments            | 172.13                      | Vs | 183.00 | **       |
| Legume (B,C) vs Legume (D,E,F)       | 182.38                      | Vs | 183.42 | ns       |
| Maize vs Rice                        | 182.75                      | Vs | 182.00 | ns       |
| Soybean, Edamame (D,E) vs Peanut (F) | 183.13                      | Vs | 184.00 | ns       |
| Soybean vs Edamame                   | 181.79                      | Vs | 184.46 | ns       |

Note: (\*\*) means a highly significant difference, and (ns) means a non-significant difference.



Based on the orthogonal contrast, the *Rhizobium spp.* treatment had a highly significant difference in ear weight without husks compared to the control, with an average of 183.00 g. *Rhizobium spp.* treatment from the edamame rhizosphere produced the highest ears without husks (184.46 g), while the control had the lowest (172.13 g). The addition of *Rhizobium spp.*, which may solubilize phosphate, is suspected to impact the weight of maize ears. Based on the availability of phosphate in the soil, which is typically in an unavailable form, a biological fertilizer agent capable of increasing the effectiveness of using P fertilizer on soils with a high concentration of bound calcium phosphate deposits is required. According to [Fitriatin et al. \(2021\)](#), organic acids created by phosphate-dissolving microorganisms might increase the solubility of unavailable P to become available P in the soil, thereby increasing P absorption by plants. Because element P is available, more photosynthetic energy can be allocated to the ear, resulting in increased ear size. Plant metabolism will also be more active, which will improve the processes of elongation, division, and cell differentiation, resulting in an increase in ear weight, length, and diameter ([Karneta et al., 2022](#)).

### 3.6 Ear dry weight

Based on the orthogonal contrast, the treatment of *Rhizobium spp.* from several rhizospheres exhibited a highly significant difference in ear dry weight compared to the control. The ear dry weight is provided in [Table 6](#).

Table 6. Ear dry weight

| Treatment                            | Ear dry weight (g) |    |        | Notation |
|--------------------------------------|--------------------|----|--------|----------|
| Control vs All treatments            | 107.75             | vs | 119.63 | **       |
| Legume (B,C) vs Legume (D,E,F)       | 115.38             | vs | 122.46 | ns       |
| Maize vs Rice                        | 117.75             | vs | 113.00 | ns       |
| Soybean, Edamame (D,E) vs Peanut (F) | 120.63             | vs | 126.13 | ns       |
| Soybean vs Edamame                   | 121.88             | vs | 119.38 | ns       |

Note: (\*\*) means a highly significant difference, and (ns) means a non-significant difference.

Based on [Table 6](#), the *Rhizobium spp.* treatment had a highly significant difference in the ear dry weight compared to the control, with an average of 119.63 g. The *Rhizobium spp.* treatment from the peanut rhizosphere produced the highest ear dry weight (126.13 g), while the control had the lowest (107.75 g). Soil microorganisms such as *Rhizobium spp.* that can dissolve are able to access legacy P, making it available to plants and thus leading to a reduction in the P fertilizer needs of crops ([de-Bashan et al., 2021](#)). According to [Calvo et al. \(2014\)](#), an increase in size, such as ear size and length, will occur as a result of improved cell division and differentiation as a form of improving plant metabolism due to efficient phosphate absorption. The ear's fresh weight is linked to its size and photosynthetic distribution. The ear maize will become bigger as it grows in size ([Hatibie et al., 2021](#)).

### 3.7 Weight of 100 seeds

Based on the orthogonal, the treatment of *Rhizobium spp.* did not have significant effect on weight of 100 seeds. The weight of 100 seeds results are provided in [Table 7](#) below.

Table 7. Weight of 100 seeds

| Treatment                            | Weight of 100 seeds (g) |    |       | Notation |
|--------------------------------------|-------------------------|----|-------|----------|
| Control vs All treatments            | 26.33                   | Vs | 26.33 | ns       |
| Graminae (B,C) vs Legume (D,E,F)     | 26.15                   | Vs | 26.44 | ns       |
| Maize vs Rice plant                  | 26.38                   | Vs | 25.93 | ns       |
| Soybean, Edamame (D,E) vs Peanut (F) | 26.91                   | Vs | 25.50 | ns       |
| Soybean vs Edamame                   | 26.70                   | Vs | 27.13 | ns       |

Note: (ns) means a non-significant difference.

Based on [Table 7](#), there was no significant difference in the weight of 100 seeds. The edamame rhizosphere (*Rhizobium spp.*) treatment produced the highest average weight of 100 seeds (27.13 g), whereas the rice plant rhizosphere had the least (25.93 g). This is apparently because the development of 100 seeds is heavily impacted by genetic factors, whereas only one type of maize was employed in this study. According to [Erawati et al. \(2021\)](#), who discovered that the weight of 100 seeds is significantly affected by genetics or the variety utilized, when different types of maize are used in maize production, the potential variance in the weight of 100 seeds is very large. Furthermore, the relationship between *Rhizobium spp.* bacteria and maize crops is not optimized, which may be one of the reasons for the underweight of 100 seeds of maize.

### 3.8 Soil phosphate content after planting

Based on the analysis of soil phosphate content after planting, the result is shown in [Table 8](#).

Table 8. Soil dissolved phosphate content after planting

| Treatment                                 | Soil dissolved phosphate (ppm) | Criteria  |
|-------------------------------------------|--------------------------------|-----------|
| Control                                   | 42.36                          | Medium    |
| Maize-rhizosphere <i>Rhizobium spp.</i>   | 86.29                          | Very high |
| Rice-rhizosphere <i>Rhizobium spp.</i>    | 63.01                          | High      |
| Soybean-rhizosphere <i>Rhizobium spp.</i> | 66.17                          | High      |
| Edamame-rhizosphere <i>Rhizobium spp.</i> | 61.63                          | High      |
| Peanuts-rhizosphere <i>Rhizobium spp.</i> | 85.29                          | Very high |

Based on [Table 8](#), The *Rhizobium spp.* treatment from the maize rhizosphere generated the highest soil dissolved phosphate content after planting (86.29 ppm), while the control had the lowest (42.36 ppm). Inoculation of *Rhizobium spp.* from the maize rhizosphere obtained the highest dissolved phosphate content. These bacteria are more adaptable to the corn root zone, resulting in a compatible symbiosis between the bacteria and the host plant due to favorable root conditions. According to [Ortiz & Sansinenea \(2022\)](#), the compatibility between bacteria and plant roots will boost bacterial activity, resulting in better nutritional content and absorption, specifically phosphate. Furthermore, each of the bacteria from different rhizospheres was capable of dissolving phosphate, whereas the control did not include *Rhizobium spp.*, resulting in the lowest soil dissolved phosphate. Phosphate-solubilizing bacteria, such as *Rhizobium spp.*, can positively interact with post-application soil conditions ([Hartati et al., 2023](#)).

## 4. Conclusion

*Rhizobium spp.* isolates from several rhizospheres (legume and non-legume) can synthesize IAA and dissolve phosphate. Soil-dissolved phosphate content increased when these bacteria were applied. Inoculation of *Rhizobium spp.* (legume and non-legume rhizospheres) showed a sig-



nificant effect on plant height, stem diameter, ear weight without husks, and ear dry weight compared to control. In addition, the plant height treated by maize-rhizosphere *Rhizobium* spp. was better than rice. It is suspected that *Rhizobium* spp. from the maize rhizosphere is more adaptable when applied to growing media for maize crops.

## Acknowledgement

The authors would like to acknowledge the support from the Research and Development Agency of the State Polytechnic of Jember, East Java, Indonesia.

## Author's declaration and contribution

The authors show no conflict of interest. All the authors have provided equal contributions to this manuscript. Similarly, the final version of the manuscript was approved by all authors.

## References

- Afzal, A., & Bano, A. (2008). Rhizobium and phosphate solubilizing bacteria improve the yield and phosphorus uptake in wheat (*Triticum aestivum*). *International Journal of Agriculture and Biology*, 10(1), 85–88. [Direct Link](#)
- Amezquita-Aviles, C. F., Coronel-Acosta, C. B., Santos-Villalobos, S. D. L., Santoyo, G., & Parra-Cota, F. I. (2022). Characterization of native plant growth-promoting bacteria (PGPB) and their effect on the development of maize (*Zea mays* L.). *Biotecnia*, 24(1), 15-22. [CrossRef](#)
- Calvo, P., Nelson, L., & Kloepper, J. W. (2014). Agricultural uses of plant biostimulants. *Plant and Soil*, 383, 3-41. [CrossRef](#)
- Celador-Lera, L., Menéndez, E., Peix, A., Igual, J. M., Velázquez, E., & Rivas, R. (2017). Rhizobium zeae sp. Nov., isolated from maize (*Zea mays* L.) roots. *International Journal of Systematic and Evolutionary Microbiology*, 67(7), 2306–2311. [CrossRef](#)
- De-Bashan, L. E., Magallon-Servin, P., Lopez, B. R., & Nannipieri, P. (2022). Biological activities affect the dynamic of P in dryland soils. *Biology and Fertility of Soils*, 58(2), 105-119. [CrossRef](#)
- Elfiati, D., Delvian, D., Hanum, H., Susilowati, A., & Rachmat, H. H. (2021). Potential of phosphate solubilizing fungi isolated from peat soils as inoculant biofertilizer. *Biodiversitas Journal of Biological Diversity*, 22(6). [CrossRef](#)
- Elhaissofi, W., Ghoulam, C., Barakat, A., Zeroual, Y., & Bargaz, A. (2022). Phosphate bacterial solubilization: A key rhizosphere driving force enabling higher P use efficiency and crop productivity. *Journal of Advanced Research*, 38 : 13-28. [CrossRef](#)
- Erawati, B. T. R., Triguna, Y., Hipi, A., & Widiastuti, E. (2021). Adaptation of superior maize varieties high yield and biomass the availability of animal feed. In *IOP Conference Series: Earth and Environmental Science* (Vol. 911, No. 1, p. 012032). IOP Publishing. [CrossRef](#)
- Fitriatin, B. N., Manurung, D. F., Sofyan, E. T., & Setiawati, M. R. (2020). Compatibility, phosphate solubility and phosphatase activity by phosphate solubilizing bacteria. *The Saudi Journal of Life Sciences*, 5(12), 281-284. [CrossRef](#)
- Fahde, S., Boughribil, S., Sijilmassi, B., & Amri, A. (2023). Rhizobia: A Promising Source of Plant Growth-Promoting Molecules and Their Non-Legume Interactions: Examining Applications and Mechanisms. *Agriculture*, 13(1279), 1-21. [CrossRef](#)
- Fu, S. F., Wei, J. Y., Chen, H. W., Liu, Y. Y., Lu, H. Y., & Chou, J. Y. (2015). Indole-3-acetic acid: A widespread physiological code in interactions of fungi with other organisms. *Plant Signaling & Behavior*, 10(8),1-30. [CrossRef](#)
- Gunasinghe, Y. H. K. I. S., & Edirisinghe, E. A. A. D. (2020). Industrially important enzyme and plant growth promoter potential of soil Actinomycetes. *International Journal for Research in Applied Sciences and Biotechnology*, 7(6), 54-62 [CrossRef](#)
- Hartati, R. D., Suryaman, M., & Saepudin, A. (2023). The effect of phosphate solubilizing bacteria at various soil pH on plant growth and yield of soybean (*Glycine max* (L.) Merr). *Journal of Agro-technology and Crop Science* 1(1) : 26-34. [Direct Link](#)

- Hatibie, S., Kaimuddin, K., & Garantjang, S. (2022). Combining Manure and Liquid Organic Fertilizer (LOF) and Its Effects on Livestock-Integrated Maize Farming Production (*Zea Mays* L.). *Hasanuddin Journal of Animal Science*, 4(1), 20-29 [CrossRef](#)
- Hussain, M. B., Zahir, Z. A., Asghar, H. N., & Mahmood, S. (2014). Scrutinizing Rhizobia to Rescue Maize Growth under Reduced Water Conditions. *Soil Science Society of America Journal*, 78(2), 538–545. [CrossRef](#)
- Karneta, R., Gultom, N. F., Meidalima, D., & Manisah, N. (2022). Growth and Yield Response of Arumba (*Zea mays* L. Ceratina) Glutinous Corn Varieties toward Ameliorants and Growth Regulators on Peatland. *Biological Research Journal*, 8(1), 36-42. [CrossRef](#)
- Kachhap, S., Chaudhary, A. N. I. T. A., & Singh, S. D. (2015). Response of plant growth promoting rhizobacteria (pgpr) in relation to elevated temperature conditions in groundnut (*Arachis hypogaea* L.). *The Ecscan*, 9(3 and 4), 771-778.
- Li, Y., Zhang, Y., Liao, P. C., Wang, T., Wang, X., Ueno, S., & Du, F. K. (2021). Genetic, geographic, and climatic factors jointly shape leaf morphology of an alpine oak, *Quercus aquifolioides* Rehder & EH Wilson. *Annals of Forest Science*, 78(3), 1-18. [CrossRef](#)
- Liu, A., Contador, C. A., Fan, K., & Lam, H. M. (2018). Interaction and regulation of carbon, nitrogen, and phosphorus metabolisms in root nodules of legumes. *Frontiers in Plant Science*, 9, 1860 [CrossRef](#)
- Mehboob, I., Naveed, M., & Zahir, Z. A. (2009). Rhizobial association with non-legumes: Mechanisms and applications. *Critical Reviews in Plant Sciences*, 28(6), 432–456. [CrossRef](#)
- Orozco-Mosqueda, Ma. del C., Santoyo, G., & Glick, B. R. (2023). Recent Advances in the Bacterial Phytohormone Modulation of Plant Growth. *Plants*, 12(3), 606. MDPI AG. [CrossRef](#)
- Ortiz, A., & Sansinenea, E. (2022). The role of beneficial microorganisms in soil quality and plant health. *Sustainability*, 14(9), 5358. [CrossRef](#)
- Pande, A., Pandey, P., Mehra, S., Singh, M., & Kaushik, S. (2017). Phenotypic and genotypic characterization of phosphate solubilizing bacteria and their efficiency on the growth of maize. *Journal of Genetic Engineering and Biotechnology*, 15(2), 379-391. [CrossRef](#)
- Qureshi, M. A., Shahzad, H., Imran, Z., Mushtaq, M., Akhtar, N., Ali, M. A., & Mujeeb, F. (2013). Potential of Rhizobium species to enhance growth and fodder yield of maize in the presence and absence of l-tryptophan. *The Journal of Animal and Plant Sciences*, 23(5), 1448-1454. [CrossRef](#)
- Rao, M. S., Prasad, P. V. N., Murthy, K. R., Sreelatha, T., & Rao, C. M. (2018) Integrated Nutrient Management in Groundnut (*Arachis hypogaea* L.)-Maize (*Zea mays* L.) Cropping System. *The Andhra Agricultural Journal*, 65 (4) : 769-778. [Direct Link](#).
- Rubio-Canalejas, A., Celador-Lera, L., Cruz-González, X., Menéndez, E., & Rivas, R. (2016). Rhizobium as potential biofertilizer of *Eruca sativa*. In *Biological nitrogen fixation and beneficial plant-microbe interaction* (pp. 213-220). Springer International Publishing. [CrossRef](#)
- Sudewi, S., Ala, A., Baharuddin, & Farid, M. (2020). The isolation, characterization endophytic bacteria from roots of local rice plant Kamba in, Central Sulawesi, Indonesia. *Biodiversitas Journal of Biological Diversity*, 21(4): 1614-1624. [CrossRef](#)
- Ventorino, V., Sannino, F., Piccolo, A., Cafaro, V., Carotenuto, R., & Pepe, O. (2014). Methylobacterium populi VP2: plant growth-promoting bacterium isolated from a highly polluted environment for polycyclic aromatic hydrocarbon (PAH) biodegradation. *The Scientific World Journal*, 2014, 1-11. [CrossRef](#)
- Yoneyama, T., Terakado-Tonooka, J., & Minamisawa, K. (2017). Exploration of bacterial N<sub>2</sub>-fixation systems in association with soil-grown sugarcane, sweet potato, and paddy rice: a review and synthesis. *Soil Science and Plant Nutrition*, 63(6), 578–590. [CrossRef](#)