International Journal of Life Science and Agriculture Research
ISSN (Print): 2833-2091, ISSN (Online): 2833-2105
Volume 03 Issue 07 July 2024
DOI: https://doi.org/10.55677/ijlsar/V03I7Y2024-14
Impact Factor: 6.774 , Page No : 596-602

Current Status and the Role of Biofilm Biofertilizer for Improving the Soil Health and Agronomic Efficiency of Maize on Marginal Soil

Itakanisa Pradmiardi Mushalin[1]*, Hidayatul Fitrah Nelma Putri[2], Hauzan Ariq Musyaffa Fajri[3], Sheni Yuniarda[4], Irwandhi[5], Fiqriah Hanum Khumairah[6], Fairus Hisanah Hibatullah[7], Debora D. M. Ambarita[8], Anne Nurbaity[9], Diyan Herdiyantoro[10], Nadia Nuraniya Kamaludin[11], Betty Natalie Fitriatin[12], Tualar Simarmata[13]
[1-13]Department of Soil Sciences and Land Resources, Faculty of Agriculture, University of Padjadjaran. Jl. Soekarno km 21, Jatinangor – West Java, Indonesia

ABSTRACT: The use of biofilm biofertilizers is emerging as a promising strategy to improve soil health and agronomic efficiency, especially for maize production on marginal soils. This review focuses on the current status and critical role of biofilm biofertilizers in improving soil properties and maize productivity. This study used Preferred Reporting Items for Systematic Reviews and Meta-Analyses using Scopus and ScienceDirect databases from 2014-2024. Results showed that current status of biofilm biofertilizer utilization is spread on azolla, rhizobacteria, and endophytic bacteria species. Biofilm biofertilizers are beneficial microbial communities encapsulated in extracellular polymeric substances (EPS) that contribute to soil structure stabilization, nutrient solubilization and improved water retention. Application of these biofertilizers has been shown to improve soil fertility by increasing organic matter content, promoting nutrient cycling, and stimulating microbial activity. These improvements result in better root development, higher plant growth rates and increased crop yields. Especially on marginal soils, where nutrient availability and soil structure are often compromised, biofilm biofertilizers offer a sustainable solution to mitigate these limitations. This review synthesizes findings from recent studies and highlights the mechanisms by which biofilm biofertilizers exert their beneficial effects, thereby highlighting their potential in sustainable agricultural practices for maize production on suboptimal soils.

KEYWORDS: Biofilm biofertilizers, soil health, maize, marginal soils, sustainable agriculture.

Published Online:
July 20, 2024

Corresponding Author:
Itakanisa Pradmiardi Mushalin

INTRODUCTION

Maize is one of commodities that serves multiple purposes such as food, feedstock for feed industry, fuel, and raw material for industry (Beding et al., 2023). Compared to wheat and rice, maize is a multipurpose crop that plays various and dynamic roles in global agricultural and food systems and food/nutrition security, making it one of the agricultural commodities with a strategic role in the economy and fulfilling human needs (Erenstein et al., 2022; Grote et al., 2021; Syahruddin et al., 2020). More than 73% of Indonesia's maize demand is used for livestock feed, 23% for household consumption, and the remainder for other industrial purposes and seed (Saragih et al., 2023).

Regions with humid tropical climates typically have low soil fertility levels, also known as marginal soil conditions. This is because macro and micro nutrients in the soil are easily leached, and organic matter decomposes rapidly, resulting in soil acidity and a deficiency of nutrients and organic material. Marginal soils include acidic soils, peat soils, and acid sulfate soils (Suwardi, 2019). In Indonesia, soils are predominantly Inceptisols, Ultisols, and Oxisols, which are classified as acidic soils. It can be concluded that acidic soils dominate in Indonesia (Suwardi, 2019; USDA, 1999).

The utilizing advancements in agricultural technology can be an effort to reduce the use of inorganic fertilizers in order to enhance soil fertility. One of the innovations in this case is the application of biofilm biofertilizers. Biofilm biofertilizers (BFBFs) consist of beneficial microorganisms organized in a biofilm matrix that has functions such as increasing nutrient availability, improving soil health, and reducing environmental impacts (Parray et al., 2017). The use of BFBFs is claimed to restore the sustainability of degraded agroecosystems and increase crop yields by reducing the use of chemical fertilizers (Dharma-wardana et al., 2023). Recognizing its potential for agriculture, biofilm biofertilizers have been explored to enhance the growth of corn plants.

The mechanism of biofilm biofertilizer preparation begins with the attachment of bacteria to the substrate with adhesive strength followed by the rapid propagation of microorganisms resulting in the formation of microcolonies. Transcription of specific genes in bacterial cells that communicate with each other now leads to the production of extracellular polymeric substances (EPS) comprising carbohydrates, proteins, nucleic acids, and fats. Attachment initiates the synthesis of an extracellular matrix at the site where the sessile bacteria are embedded, followed by the formation of a water-filled channel. As the thickness of EPS increases, anaerobic conditions develop in the biofilm and newly formed daughter cells are cut through enzymatic action on polysaccharide (Mondal et al., 2020; Ansari et al., 2012). In some cases, bacteria stop producing EPS and release it into the environment due to "quorum sensing", which allows communication between intra-species and inter-species.
Considering the important role of biofilm biofertilizer, the primary aim of this article is to reveal the current status and role of biofilm biofertilizers in improving soil health and agronomic efficiency of maize on marginal soil.

METHODOLOGY

Data for this bibliometric analysis were collected from Scopus and ScienceDirect database. The search terms and their combinations used “biofilm”, "biofertilizer”, “maize”, “soil”, “health”, and “marginal”. The search was limited to research articles with date of publication 2014-2024. Language of publication was limited to English. The detailed search strategy is outlined in Table 1. Data were assessed using Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow guidelines or Systematic Literature Review (Page et al., 2021) (Figure 1). Duplications were eliminated using Mendeley Reference Manager 2.107.0. Eligibility of the documents included was based on the abstract related to the topic of the article, documents not related to the topic were categorized as ineligible thus not included for further content analysis.

Table 1: Search strategy used to retrieve relevant research articles

Search Strategy	Scopus	ScienceDirect
Biofilm AND biofertilizer	21	50
Biofilm AND biofertilizer AND maize	2	22
Biofilm AND biofertilizer AND soil AND health	3	18
Biofilm AND biofertilizer AND marginal AND soil	-	2
Biofilm AND biofertilizer AND maize AND marginal	-	11

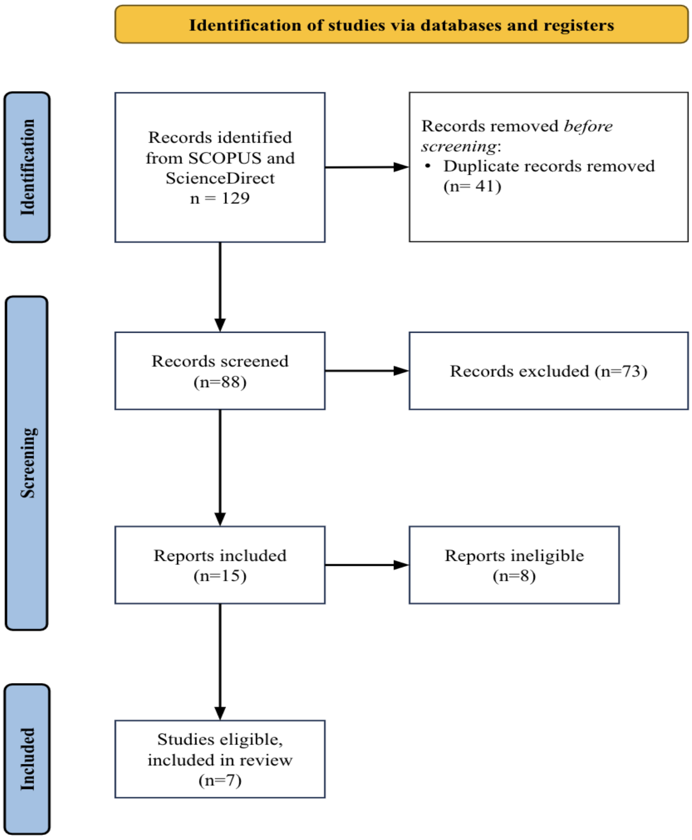

Figure 1: PRISMA flowchart reporting the article selection process for the systematic literature review

RESULTS AND DISCUSSION

Result of PRISMA analyses

A literature search conducted on the Scopus and ScienceDirect databases using the combination of keywords "biofertilizer", "biofilm", "maize", "marginal", "soil", and "health" over the past 10 years resulted in 88 research articles. After cleaning the data for duplicates and ineligible entries, only the relevant articles remained.

Microbe	Benefit	Reference
Cyanobacterial consortium and Anabaena sp.–Trichoderma sp	Available soil nitrogen 40%–44% increment, significance effect on dry weight plant	Prasanna et al., 2016
Anabaena laxa and Anabaena – Rhizobium	Increase 50% yield	Bidyarani et al., 2016
Aspergillus sp. and Enterobactor sp	Efficiency anorganic fertilizer up to 39%, increase, Increase fruit quality and economic benefit 152%	Singhalage et al., 2019
Bacillus sp. and biochar	Increases biofertilizer resistance to extreme temperatures and environments	Ajeng et al., 2023
Bacillus cereus and Bacillus thuringiensis	Increase plant growth and enhance grain yield by 37% and 31% of wheat	Zahra et al., 2023
Micrococcus yunnanensis	Improved rice growth in morphological and biochemical aspects	Majhi et al., 2024
Rhizobium	Increase in seed germination rate, length and dry biomass of plant organs and seed components	Saleem & Khan, 2023

The table presents studies demonstrating the beneficial effects of different microbial consortia on plant growth and yield. A cyanobacterial consortium and Anabaena sp.–Trichoderma sp increased available soil nitrogen by 40%-44% and significantly improved plant dry weight (Prasanna et al., 2016). Anabaena laxa and Anabaena–Rhizobium enhanced yield by 50% (Bidyarani et al., 2016), while Aspergillus sp. and Enterobacter sp. improved inorganic fertilizer efficiency by 39% and increased fruit quality and economic benefits by 152% (Singhalage et al., 2019). Bacillus sp. and biochar increased biofertilizer resistance to extreme conditions (Ajeng et al., 2023), and Bacillus cereus and Bacillus thuringiensis boosted wheat growth and yield by 37% and 31% (Zahra et al., 2023). Micrococcus yunnanensis enhanced rice growth morphologically and biochemically (Majhi et al., 2024), and Rhizobium improved seed germination, plant length, and biomass (Saleem & Khan, 2023). These findings highlight the potential of microbial consortia to enhance plant growth, yield, and resilience to environmental stresses, underscoring their importance in sustainable agriculture.

Role of Biofilm Biofertilizers

Microbial biofilms are important in agriculture because they promote plant health, maintain soil structure, and improve water retention by forming soil aggregates. Studies by Alami et al. (2000), Sandhya et al. (2009), and Deka et al. (2019) highlight their role in improving nutrient composition, solubilization, and availability, which are critical for plant growth (Lee et al., 2008; Wani & Khan, 2010; Malviya et al., 2011; Wang et al., 2014; Pérez-De-Luque et al., 2017). In addition, microbial biofilms contribute to carbon sequestration, nitrogen fixation, and overall improvement of soil fertility (Hafeez et al., 2000; Rinaudi & Giordano, 2010; Prasanna et al., 2016).

Soil structure, a critical aspect of soil health, influences nutrient availability and organic matter content. Soil aggregates, formed by bound soil particles, determine key soil properties such as porosity, hydraulic conductivity, and water-holding capacity. Plant mucilage and microbial extracellular polymeric substances (EPS) are critical for stabilizing soil aggregates and increasing organic matter content (Watt et al., 1993). Research, including that of Bagde et al. (2011), shows that soils treated with biofilm biofertilizers have greater aggregate stability, improved aeration, root penetration, and overall soil health. These improvements create a resilient soil ecosystem that can withstand environmental stresses such as drought and heavy rainfall.

Microorganisms are essential in soil ecosystems for nutrient cycling and regulating biotic interactions. Diverse microbial communities improve soil fertility by mobilizing nutrients, producing growth regulators, and increasing the stability of soil structure (Zakeel and Safeena, 2019). This microbial diversity significantly supports sustainable agriculture by increasing nutrient availability, plant stress tolerance, and overall soil health (Dewi et al., 2023).

Biofilm Biofertilizer on Maize Agronomic Efficiency

Biofilm biofertilizers can potentially have significant effects on root development and nutrient uptake efficiency in maize plants. Beneficial biofilms developed by nitrogen fixing bacteria and P - solubilising fungi in vitro conditions and also used as biofertilizers in non - leguminous crops and also observed that the bacteria colonized fungal mycelia to form biofilms (Zakeel, M., et.al., 2019). The biofilms showed high rates of biological nitrogen fixation and organic acid production which directly influences the synthesis of indole acetic acid like substances than microbes when used as monocultures (Seneiviratne et al., 2003). Biofilmed biofertilizers were more effective, highly responsive and more persistent under pot culture conditions when compared to individual cultures and control. The better ability of these biofilms was due to its higher PGPR activity, strongest interaction between bacteria and fungi and resistant to different environmental conditions which influenced the maize crop (Babu, S., et.al., 2017).

Dicho and Verma (2014) inoculated Maize seeds by dipping in single solution of each bacterium containing 108 cfu ml-1 and the control seeds were dipped in sterilized water. The highest germination percentage was obtained from seed inoculated with Azospirillum spp. This treatment had also best root length. The maximum height of plants was observed with seeds treated with Pseudomonas spp 1 with an increase of 69.85 percent. The highest shoot and root dry biomass were also recorded with Pseudomonas spp 1 (florescent) with an increase of 64.67 percent and 49.67 percent respectively as compared to control. These results suggest that specific combinations of PGPR can be considered as efficient alternative biofertilizers to promote maize seed germination, biomass and crop yield.

Significant enhancement in microbial activity, facilitated through increases in photosynthetic biomass (chlorophyll as an index of cyanobacterial inoculation), microbial bio- mass carbon and soil proteins attest to their critical role in soil fertility, thereby improved plant growth.

A biofilm is a colony of microorganisms and the extracellular polymeric substances (EPS) that the local bacterial population releases to defend the community. In addition to increasing crop output and improving soil quality, the use of biofilm fertilizer can restore the livability of soil that has been compromised by conventional farming systems (Rathnathilaka et al., 2022). The investigation conducted on the interactions of maize inbreds with cyanobacterial consortium and cyanobacte- rium-fungus biofilms, illustrated its beneficial impact on plant growth parameters and environmental, economic and energy efficiency. It was demonstrated that cyanobacterial inoculation, not only results in 25% savings of N fertiliz- ers, but also leads to greater environmental, economical and energy resilience, and thereby, serves as an efficient and effective growth stimulating option for this high-value crop.

Challenges and Future Perspective

The use of biofilm biofertilizer to improve the soil health and maize production on marginal soil faces several challenges including technical aspects, government policy, public and farmer education, and production costs.

Microbes ability to adapt to environmental conditions differs between laboratory and field settings. Further research is needed to evaluate the viability, formulation, and optimal application methods of biofilm biofertilizers. Additionally, a deep understanding of the interaction between microbes and maize plants, as well as environmental factors such as soil moisture, pH, and nutrient availability, is crucial for careful consideration. This is necessary to ensure that applied microbes can successfully adapt to field soil and climate conditions.

The complex and time-consuming regulatory process can be a barrier to the development and adoption of this technology by farmers. Consistent and clear policy support from the government, including fiscal incentives, technical assistance, and research and development support, is essential to facilitate widespread use of biofilm biofertilizers.

Moreover, educating communities and farmers about the benefits and applications of biofertilizers is another challenge that needs to be overcome. Limited knowledge about this new technology and its application methods can slow down adoption by farmers, despite its significant long-term benefits. Effective education programs tailored to local needs can help improve understanding and acceptance of this technology.

Production costs are also a significant consideration. High production costs for manufacturing and applying biofertilizers can hinder farmers, especially in regions with limited resources. Innovations in production technology and the use of local raw materials can help reduce production costs and make this technology more affordable for farmers.

By overcoming these challenges, the use of biofilm biofertilizers in maize cultivation can make a significant contribution to enhancing the soil health agricultural productivity sustainably and reducing dependency on chemical inputs.

Due to the unregulated overuse of chemical fertilizers by farmers during intensive agricultural practices, soils have become deficient in nutrients, particularly phosphorus, leading to soil degradation. As a result, scientists are investing significant time and effort into discovering methods to help agricultural plants thrive with reduced dependence on traditional inorganic fertilizers. Collaboration among various experts, including economists, plant breeders, plant pathologists, nutritionists, and soil microbiologists, will be essential for conducting research initiatives in the short, medium, and long term.

As the agricultural sector faces increasing challenges due to soil degradation, climate change, and the need for sustainable practices, biofilm biofertilizers present a promising solution for enhancing soil health and agronomic efficiency, particularly in maize cultivation on marginal soils.

The future prospects for biofilm biofertilizers, highlighting potential advancements and their implications for sustainable agriculture as follows:

a. Technological Advancements
Enhanced Formulations: Future research will focus on developing enhanced biofilm biofertilizer formulations with improved stability, efficacy, and targeted delivery systems. Integration with Precision Agriculture: Integrating biofilm biofertilizers with precision agriculture tools such as drones and automated irrigation systems can optimize application and improve efficiency.

b. Sustainable Agricultural Practices
Synergistic Use with Organic Amendments: Combining biofilm biofertilizers with organic amendments such as compost and biochar can further improve soil health and crop productivity.
Reduction in Chemical Inputs: The use of biofilm biofertilizers can reduce the reliance on chemical fertilizers and pesticides, promoting more sustainable and eco-friendly farming practices.

c. Policy and Institutional Support
Incentives and Subsidies: Governments and agricultural agencies should provide incentives and subsidies to encourage the adoption of biofilm biofertilizers among maize farmers.
Research and Development: Increased investment in research and development is essential to advance biofilm biofertilizer technology and its applications.

CONCLUSION

Biofilm biofertilizers are an emerging and promising solution for enhancing maize cultivation on marginal soils, characterized by poor fertility, high salinity, and acidity. Current research indicates that these biofertilizers significantly improve soil health by enhancing nutrient solubilization, stress tolerance, and microbial diversity, while also improving soil structure and stability. Results of this review showed that current status of biofilm biofertilizer utilization is spread on azolla, rhizobacteria, and endophytic bacteria species. Additionally, biofilm biofertilizers have been shown to boost the agronomic efficiency of maize by improving plant growth, yield, and nutrient use efficiency, making them a valuable tool for sustainable agriculture in challenging soil conditions. The challenges of using biofilm biofertilizer for sustainable agriculture technical aspects, government policy, public and farmer education, and production costs. future prospects of using biofilm

REFERENCES

1. Ajeng, A. A., Abdullah, R., & Ling, T. C. (2023). Biochar-Bacillus consortium for a sustainable agriculture: physicochemical and soil stability analyses. Biochar, 5(1), 17.
2. Alami, Y., Achouak, W., Marol, C., & Heulin, T. (2000). Rhizosphere soil aggregation and plant growth promotion of sunflowers by an exopolysaccharide-producing Rhizobium sp. strain isolated from sunflower roots. Applied and Environmental Microbiology, 66(8), 3393–3398.
3. Ansari MI, Schiwon K, Malik A and Grohmann E. (2012). Biofilm formation by environmental bacteria. In: Environmental Protection Strategies for Sustainable Development, 341-377.
4. Babu, S. V., Triveni, S., Reddy, R. S., & Sathyanarayana, J. (2017). Persistence of PSB-fungi biofilmed biofertilizer in the soils and its effect on growth and yield of maize. International Journal of Current Microbiology and Applied Sciences, 6(12), 1812-1821.
5. Bagde, U. S., Prasad, R., & Varma, A. (2011). Role of microbial biofilms in agriculture: Perspectives on plant and soil health. SpringerLink.
6. Beding, P. A., Lewaherilla, N. E., Lestari, R. H., & Tirajoh, S. (2023). Analisis Potensi Pengembangan Komoditas Jagung Di Wilayah Perbatasan Nkri – Png Kabupaten Keerom Papua. SEPA: Jurnal Sosial Ekonomi Pertanian Dan Agribisnis, 20(2), 162. doi: 10.20961/sepa.v20i2.52339
7. Bidyarani, N., Prasanna, R., Babu, S., Hossain, F., & Saxena, A. K. (2016). Enhancement of plant growth and yields in Chickpea (Cicer arietinum L.) through novel cyanobacterial and biofilmed inoculants. Microbiological Research, 188-189, 97–105.

8. Deka, P., Goswami, G., Das, P., Gautom, T., Chowdhury, N., Boro, R. C., & Barooah, M. (2019). Bacterial exopolysaccharide promotes acid tolerance in Bacillus amyloliquefaciens and improves soil aggregation. Molecular Biology Reports, 46(1), 1079–1091.
9. Dewi, W. S., et al. (2023). Microbial biofilm for soil health, plant growth, and productivity under multi stress: A review. IOP Conference Series: Earth and Environmental Science, 1162, 012008.
10. Dharma-wardana, M.W.C., Waidyanatha, P., Renuka, K.A., Abeysiriwardena, D. and Marambe, B. (2023). A critical examination of crop-yield data for vegetables, maize and Tea for commercialized Sri Lankan biofilm biofertilizers. arXiv preprint arXiv:2307.16283.
11. Dicho, A.H and Verma, R.K. 2014. Effect of growth promoting microbes on intial growth of maize. Indian Journal Tropical Biodiversity. 22(1): 64-69.
12. Erenstein, O., Jaleta, M., Sonder, K., Mottaleb, K., & Prasanna, B. M. (2022). Global maize production, consumption and trade: trends and R&D implications. Food Security, 14(5), 1295–1319. doi: 10.1007/s12571-022-01288-7
13. Grote, U., Fasse, A., Nguyen, T. T., & Erenstein, O. (2021). Food Security and the Dynamics of Wheat and Maize Value Chains in Africa and Asia. Frontiers in Sustainable Food Systems, 4(February), 1–17. doi: 10.3389/fsufs.2020.617009
14. Hafeez, F. Y., Shah, N. H., & Malik, K. A. (2000). Field evaluation of lentil cultivars inoculated with Rhizobium leguminosarum bv. Viciae strains for nitrogen fixation using nitrogen-15 isotope dilution. Biology and Fertility of Soils, 31(1), 65–69.
15. Lee, K. H., Koh, R. H., & Song, H. G. (2008). Enhancement of growth and yield of tomato by Rhodopseudomonas sp. under greenhouse conditions. Journal of Microbiology, 46(6), 641–646.
16. Majhi, K., Let, M., & Bandopadhyay, R. (2024). Efficacious use of Micrococcus yunnanensis GKSM13 for the growth of rice seedlings under copper stress with elucidation into genomic traits. Current Plant Biology, 37, 100318.
17. Malviya, J., Singh, K., & Joshi, V. (2011). Effect of phosphate solubilizing fungi on growth and nutrient uptake of groundnut (Arachis hypogaea) plants. Journal of Applied Sciences Research, 2(2), 110–113.
18. Mondal, K., Chakraborty, A. (2020). Biofilm: a next-generation bio-fertilizer. KRISHI SCIENCE-eMagazine for Agricultural Sciences, 01(3), 6-9.
19. Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., ... & Moher, D. (2021). Updating guidance for reporting systematic reviews: development of the PRISMA 2020 statement. Journal of clinical epidemiology, 134, 103-112. https://doi.org/10.1016/j.jclinepi.2021.02.003
20. Parray, JA, S Jan, AN Kamili, RA Qadri, & K Hegde, (2017). Biofilm: A Hidden Treasure of Plant Microbe Interactions. Microbiological Research.
21. Pérez-De-Luque, A., Tille, S., Johnson, I., Pascual-Pardo, D., Ton, J., & Cameron, D. D. (2017). The interactive effects of arbuscular mycorrhiza and plant growth-promoting rhizobacteria synergistically enhance host plant defences against pathogen. Scientific Reports, 7, 1–10. https://doi.org/10.1038/srep46888
22. Prasanna, R., Kanchan, A., Kaur, S., Ramakrishnan, B., Ranjan, K., Singh, M. C., Hasan, M., Saxena, A. K., & Shivay, Y. S. (2016). Chrysanthemum Growth Gains from Beneficial Microbial Interactions and Fertility Improvements in Soil Under Protected Cultivation. Horticultural Plant Journal, 2(4), 229-239.
23. Rathnathilaka, T, M Premarathna, S Madawala, A Pathirana, K Karunaratne, & G Seneviratne, 2022. Biofilm biofertilizer application rapidly increases soil quality and grain yield in large scale conventional rice cultivation: a case study. Journal of Plant Nutrition, 0: 1–11. Taylor & Francis.
24. Rinaudi, L. V., & Giordano, W. (2010). An integrated view of biofilm formation in rhizobia. FEMS Microbiology Letters, 304(1), 1–11.
25. Saleem, S., & Khan, M. S. (2023). Phyto-interactive impact of green synthesized iron oxide nanoparticles and Rhizobium pusense on morpho-physiological and yield components of greengram. Plant Physiology and Biochemistry, 194, 146-160.
26. Sandhya, V., Ali, S. K. Z., Grover, M., Reddy, G., & Venkateswarlu, B. (2009). Alleviation of drought stress effects in sunflower seedlings by the exopolysaccharides producing Pseudomonas putida strain GAP-p45. Biology and Fertility of Soils, 46(1), 17–26.
27. Saragih, D. Y. E., Natalia, H., Pradityao, P. S., & Astuti, M. (2023). Pemanfaatan Jagung Lokal Oleh Industri Pakan Tahun 2022 (Vol. 4). Direktorat Jenderal Peternakan dan Kesehatan Hewan Kementerian Pertanian Republik Indonesia.
28. Seneviratne, G. (2003). “Development of eco-friendly beneficial microbial biofilms”. Curr. Sci. 85: 1395-1396.
29. Singhalage, I.D., Seneviratne, G., Madawala, H.M.S.P., & Wijepala, P.C. (2019). Profitability of strawberry (Fragaria ananassa) production with biofilmed biofertilizer application. Scientia Horticulturae, 243, 411-413.
30. Suwardi. (2019). Utilization and Improvement of Marginal Soils for Agricultural Development in Indonesia. IOP Conference Series: Earth and Environmental Science, 383(1). doi: 10.1088/1755-1315/383/1/012047

31. Syahruddin, K., Azrai, M., Nur, A., Abid, M., & Wu, W. Z. (2020). A review of maize production and breeding in Indonesia. IOP Conference Series: Earth and Environmental Science, 484(1). doi: 10.1088/1755-1315/484/1/012040
32. USDA. (1999). Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys. In Archiv für Elektrotechnik (2nd ed., Vol. 45, Issue 4). United States Department of Agriculture Natural Resources Conservation Service. doi: 10.1007/BF01574372
33. Wang, X., Cao, Y., Tang, X., Ma, X., Gao, J., & Zhang, X. (2014). Rice endogenous nitrogen fixing and growth promoting bacterium Herbaspirillum seropedicae DX35. Acta Microbiologica Sinica, 54(3), 292–298.
34. Wani, P. A., & Khan, M. S. (2010). Bacillus species enhance growth parameters of chickpea (Cicer arietinum L.) in chromium stressed soils. Food and Chemical Toxicology, 48(12), 3262–3267.
35. Watt, M., McCully, M.E., & Jeffree, C.E. (1993). Plant and bacterial mucilages of the maize rhizosphere: Comparison of their soil binding properties and histochemistry in a model system. Plant Soil, 151, 151-165.
36. Zahra, S. T., Tariq, M., Abdullah, M., Azeem, F., & Ashraf, M. A. (2023). Dominance of Bacillus species in the wheat (Triticum aestivum L.) rhizosphere and their plant growth promoting potential under salt stress conditions. PeerJ, 11, e14621.
37. Zakeel, M. C. M., & Safeena, M. I. S. (2019). Biofilmed biofertilizer for sustainable agriculture. Plant Health Under Biotic Stress: Volume 2: Microbial Interactions, 65-82.