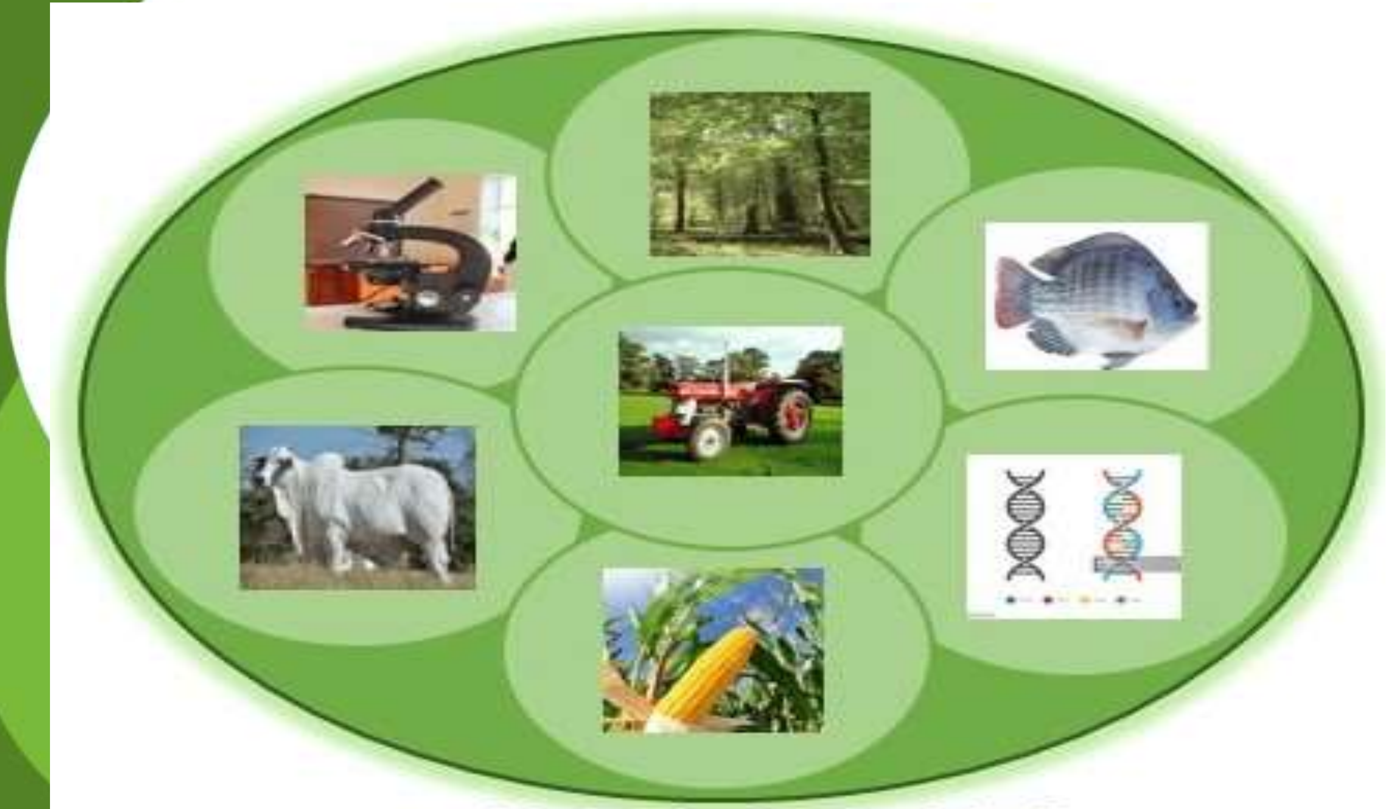
(KEJAANS)

KEBBI JOURNAL OF AGRICULTURE AND NATURAL SCIENCES

January, 2025 Vol. 1, issue 1



KEJAANS

CONTACT:
The Editor,
Kebbi Journal of Agriculture and Natural Sciences,
Faculty of Agriculture,
Kebbi State University of Science and Technology Aliero,
PMB 1144, Birnin kebbi, Nigeria.
Email: kejaanseditor@ksusta.edu.ng, kejaans.foa@gmail.com.
Phone: +234 8039370546

ISSN: 1595-5776

KEBBI JOURNAL OF AGRICULTURE AND NATURAL SCIENCES

(KEJAANS)

JANUARY, 2025: Volume 1, Issue 1

OFFICIAL JOURNAL OF THE

FACULTY OF AGRICULTURE

KEBBI STATE UNIVERSITY OF SCIENCE AND TECHNOLOGY, ALIERO

ISSN: 1595-5776

About the Journal

This official scientific publication of the Faculty of Agriculture, Abdullahi Fodiyo University of Science and Technology Aliero, is a non-profit, open access, double-blind peer-reviewed Journal publishing four issues (January, April, July and October) per annum. The Journal is a platform open to collaborations with researchers, authors, institutions, research agencies and private companies related to Agriculture. The Mission of the Journal is to disseminate scientific knowledge through the publication of original research articles, research notes, book reviews, letters to the editor and reviews of Literature, representing a contribution to scientific and technological knowledge in respective areas covered by the Journal. The Kebbi Journal of Agriculture and Natural Sciences seeks to validate and disseminate new knowledge, making it public in order to strengthen the human capacity, constitute a link in the scientific community to the society and encouraging the expansion of University and academic researches.

Scope of Kebbi Journal of Agriculture and Natural Sciences (KEJAANS)

The Kebbi Journal of Agriculture and Natural Sciences has the sole aim of providing an intellectual platform and ideas for scholars, by promoting interdisciplinary studies related to agriculture and natural science through publishing the latest scientific research findings that are of direct policy implications and beneficial to the research community. Consequently, the journal covers all aspects of Crop Science, Animal Science, Agricultural Economics, Agricultural Extension and Rural Development, Food Science, Fisheries and Aquaculture, Biotechnology, Soil Science and Agricultural Engineering, Forestry and Environment, Wildlife, Agricultural Education, Agro-allied Industries as well as all Natural Science researches related to Agriculture.

KEBBI JOURNAL OF AGRICULTURE AND NATURAL SCIENCES (KEJAANS)
JANUARY, 2025: Volume 1, Issue 1: 238-246
p-ISSN: 1595-5776

ROLES OF *BACILLUS MUCILAGINOSUS* AND *BACILLUS LICHENFORMIS* IN ENHANCING SOIL PHOSPHOROUS SOLUBILIZATION AMENDED WITH RICE HUSK

Abubakar, G.A. and Lawal Abdullahi

Department of Soil Science and Land Resources Management, Faculty of Agriculture, Usmanu Danfodiyo University, Sokoto, Nigeria

Corresponding Author email: garba.aliyu@udusok.edu.ng +23408062662255

ABSTRACT

The study was conducted to investigate the influence of Bacillus mucilaginosus and Bacillus lichenformis on soil soil available phosphorus amended with rice husk, at Usmanu Danfodio University Teaching and Research Fadama Farm Kwalkwalawa, Wamakko Local Government Area, Sokoto State Nigeria, the samples were collected at a depth of 0-30cm with the aid of Auger to make a composite from each treatment, these was replicated three times, a total of 36 samples were collected, the soil samples were analyzed for available phosphorous, and Soil pH in the laboratory. The result shows that there were significant difference ($P \leq 0.05$). Combination of Rice husk + B. mucilaginosus and B. lichenformis with a mean pH of (6.80), Rice husk alone has a mean pH of (6.69) and control has the lowest mean pH of (6.17), which are all slightly acidic. Rice husk + B. mucilaginosus and B. lichenformis recorded the highest soil available phosphorus with a mean of (0.60 g/kg) which is high, followed by Rice husk alone with a mean of (0.52 g/kg) which is also high and control has the lowest mean (0.28 g/kg). The use of B. mucilaginosus and B. lichenformis ameneded with rice husk in agricultural practices enhance soil pH and phosphorous availability and improve soil quality, which may ultimately lead to increase in crop yields.

Keywords: Bacillus mucilaginosus, Bacillus lichenformis, Phosphorous, pH, Rice husk, Inoculation.

Introduction

Bacillus mucilaginosus and *Bacillus lichenformis* are two beneficial bacteria that play a significant role in enhancing soil phosphorus solubilization. Their properties and applications can vary significantly, depending on the specific strain and context in which they are found or used (Richts *et al.*, 2019; Chen *et al.*, 2021; AL-qasy and Al-Shammari, 2022). *Bacillus mucilaginosus* has been shown to increase soil pH value, reduce soil acidity, and increase the content of exchangeable phosphorus, active organic phosphorus, and inorganic phosphorus (AL-qasy and Al-Shammari, 2022). This bacterium can also prolong the phosphorite-dissolving time, making phosphorus more available to plants, hence they can be used as biofertilizers to enhance soil phosphorus solubilization and promote plant growth (Thomas *et al.*, 2018).

Phosphorus is an essential element responsible for plant growth. Available phosphorus refers to the amount of phosphorus that can be absorbed by crop plants (Liu *et al.*, 2021) Phosphorus is an important macro nutrient element which has been observed to limit crop productivity (Mishra *et al.,* 2017). Phosphorus deficiency is widely considered the main biophysical constraint to food production in large areas of farmland in sub humid and semi-arid Africa (Singh *et al*., 2014; Mshari *et al*., 2019).Phosphorus availability in soil is often limited, and the ability of *B. mucilaginosus* and *B. lichenformis* can solubilize phosphorus adds another layer to their plant growth-promoting capabilities. The production of phosphatase enzymes allows these bacteria to break down complex phosphorus compounds, enhancing the availability of this nutrient for plant uptake (Yu *et al*., 2023). This potential reduction in the reliance on chemical phosphorus fertilizers aligns with the principles of sustainable agriculture.

Phosphorus is an essential nutrient for plant growth, as it is a key component of DNA, RNA, and ATP molecules. However, phosphorus can be limiting for plant uptake in certain soil conditions (Selzer & Schubert, 2021). Here are some reasons why: Low phosphorus content in soil: Phosphorus is not as abundant in soil as other nutrients like nitrogen and potassium. In many soils, the phosphorus content is low, making it difficult for plants to access the nutrient they need (Fu *et al*., 2020). Phosphorus fixation: Phosphorus can become fixed in soil, making it unavailable for plant uptake. This process is known as phosphorus fixation and is caused by microbes that bind phosphorus to organic matter or minerals in the soil. The fixed phosphorus is then unavailable for plant uptake until it is released through weathering or other processes (Wissuwa *et al*., 2020).

The availability of phosphorus in soil is strongly influenced by soil pH. Phosphorus is most available at neutral to slightly acidic pH levels (6.0-7.5), but becomes less available at both very acidic and very alkaline pH levels. In acidic soils, phosphorus can become fixed to aluminum and iron minerals, making it unavailable for plant uptake (Chen *et al*., 2023). In alkaline soils, phosphorus can become fixed to calcium minerals, also making it unavailable for plant uptake (Hou *et al*., 2018). Leaching: Phosphorus can be leached from soil through water movement, particularly in sandy soils with low organic matter content. This can result in a depletion of phosphorus in the root zone and make it difficult for plants to access the nutrient they need (Vermeiren *et al*., 2021).

Microbial competition: Microbes in soil can compete with plants for phosphorus uptake, particularly during periods of low phosphorus availability. This competition can result in reduced phosphorus uptake by plants and limit their growth and development (Amadou *et al*., 2022). Improving phosphorus (P) availability in soils is essential for promoting healthy plant growth and maximizing crop yields (Moro *et al*., 2021).

Phosphorus-solubilizing bacteria (PSB): PSB are a group of bacteria that can mobilize fixed P by producing organic acids and enzymes that help break down organic matter and release P into the soil. Farmers can introduce PSB into the soil through the use of inoculants or by planting PSB-rich cover crops (Hussain, 2019). Precision agriculture: Precision agriculture techniques like variable rate fertilization and site-specific nutrient management can help reduce over-application of P fertilizers, reducing waste and minimizing environmental impacts. By applying P fertilizers only where they are needed most, farmers can improve P availability while minimizing costs and environmental impacts (Skrzypczak *et al*., 2022). Phosphorus (P) is an essential nutrient for plant growth, but it is often limited in soil due to fixation and low availability. Microorganisms play a crucial role in making P available to plants by mobilizing fixed P and releasing it into the soil. One group of microorganisms responsible for P availability is phosphorus-solubilizing bacteria (PSB) (Saadouli *et al*., 2021).

KEBBI JOURNAL OF AGRICULTURE AND NATURAL SCIENCES (KEJAANS)
JANUARY, 2025: Volume 1, Issue 1: 238-246
p-ISSN: 1595-5776

PSB are a diverse group of bacteria that can solubilize fixed P by producing organic acids, enzymes, and other compounds that help break down organic matter and release P into the soil. These bacteria can also help increase soil pH by producing alkaline compounds, making P more available for plant uptake (Hussain, 2019). Some examples of PSB include Bacillus, Pseudomonas, and Aspergillus species. These bacteria can be found in soil, water, and plant rhizospheres, where they play a vital role in nutrient cycling and plant growth promotion. PSB can benefit crops in several ways. Firstly, they can increase P availability in the soil, making it more accessible to plants. This can result in improved crop yields and reduced fertilizer requirements. Secondly, PSB can help reduce the buildup of fixed P in the soil, which can lead to environmental problems like eutrophication and water pollution. Thirdly, PSB can help improve soil structure and promote beneficial microbial communities, which can lead to improved soil health and reduced erosion (Li *et al*., 2017).

To harness the benefits of PSB, farmers can introduce these bacteria into the soil through the use of inoculants or by planting PSB-rich cover crops. By promoting PSB activity in the soil, farmers can improve P availability, reduce fertilizer requirements, and promote healthy plant growth. Phosphorus-solubilizing bacteria (PSB): These bacteria can solubilize fixed P by producing organic acids, enzymes, and other compounds that help break down organic matter and release P into the soil. Examples of PSB include Bacillus, Pseudomonas, and Aspergillus species (Hussain, 2019).

Phosphate-accumulating organisms (PAOs) can accumulate large amounts of P in their cells and release it slowly over time, making it available to plants during periods of low P availability which include Acidiphilium and Bacillus species (Li *et al*., 2020).

The integration of rice husk as a bio-amendment adds a novel dimension to the discussion. Rice husk, an abundant byproduct of agriculture, is rich in carbon and silica. When combined with Bacillus species, it creates synergistic effects (Kovar & Cantarella, 2019). The carbon content of rice husk complements the extracellular enzymes produced by the bacteria, enhancing organic matter decomposition and nutrient cycling. Simultaneously, the silica content contributes to improved soil structure and water retention (Gill & Jalota, 2021). Rice husk, the outer protective layer of rice grains, is a byproduct of rice milling that has gained increasing attention in recent years due to its potential as a soil amendment (Kong & Lu, 2022).

Rice husk has been shown to improve soil structure and aggregation, which are critical factors for soil health and water retention. Oppong Danso *et al.,* (2021) reported that the addition of rice husk to soil increased the soil porosity, water-holding capacity, and aeration, resulting in enhanced root growth and nutrient uptake by crops. Microbial activity: Rice husk contains organic matter that can serve as a source of carbon for soil microbes, promoting their activity and nutrient cycling (Linam *et al.,* 2023). The incorporation of rice husk into soil increased the population of beneficial microbes such as mycorrhizal fungi and nitrogen-fixing bacteria, leading to improved plant growth and yield (Ebe, 2020). Nutrient availability: Rice husk can also enhance nutrient availability in soil by providing a slow-release source of essential nutrients such as potassium, phosphorus, and calcium, the addition of rice husk to soil increased the availability of these nutrients, resulting in higher crop yields and reduced fertilizer requirements (Xiang *et al.,* 2023).

Nigeria, being an agricultural nation, heavily relies on rice production for food security and economic growth (Aihonsu & Adesini, 2006). However, the efficient utilization of nutrients in soil, particularly nitrogen, carbon, and phosphorus, is crucial for sustainable rice cultivation. Traditionally, chemical fertilizers have been used to meet the nutrient requirements of crops. However, this approach raises concerns about environmental sustainability and long-term soil health.

By harnessing the potential of these beneficial bacteria, we can reduce our reliance on chemical fertilizers and promote sustainable agricultural practices (He et al., 2023). Understanding the influence of these bacteria on nutrient availability in soil will not only contribute to sustainable rice production but also provide valuable insights for the agricultural sector in Nigeria. It has the potential to improve soil health, increase crop productivity, and reduce the environmental impact of conventional farming practices (Delfim et al., 2018).

The main objective is to study the influence of the *B. mucilaginosus* and *B. lichenformis* on soil availale phosphorous and pH using rice husk as a soil amendment. This Investigation is geared towards advancing sustainable agricultural methodology by enhance nutrient availability, optimize resource utilization, and fostering overall soil health, reducing chemical fertilizer use, optimize resource management by repurposing rice husk, and contribute to long-term fertility and ecosystem sustainability.

Material and Methods

The study was conducted at University Fadama Teaching and Research Farm in Kwalkwalawa, Wammako Local Government Area, Sokoto State Nigeria. Sokoto State is located at Latitudes 13°1^{I} North and Longitude 5°15^{I} East. The vegetation of the area is semi-arid with an average rainfall of 655.85mm, with a relative humidity of 48.54 between mid-May to early June, and reaches it peaks in August or September. The average temperature is 30^{o}C. The dry season starts in mid-October and ends in April, while the coldest months are November to January which is characterized by dry hamattan wind (NIMET, 2022). The treatments consisted of control, Rice husk alone, rice husk + *B. mucilaginosus* and *B. lichenformis*, which were replicated three times, Randomized Complete Block Design (RCBD). Soil samples were inoculated with strains of *B. mucilaginosus* and *B. lichenformis* for a long term (42 days) after which soil samples were from the study areas, at a depth of 0-30cm with the aid of Auger to make a composite from each treatment. The soil samples collected were properly labeled and stored in clean polythene bags for easy conveyance and to prevent any contamination. Soil sample were separately air-dried and crushed using a pestle and mortar in the laboratory. The ground soil samples were sieved with 2mm sieve and the fine fractions used for the determination of soil pH and available phosphorous in the laboratory. Soil pH was determined in 1:1 soil/water suspension using a glass electrode pH meter (Henders, 1993). Available phosphorous was determined using Bray I method as described by (Bray and Kurtz, 1945). Descriptive statistics and analysis of variance (ANOVA) is used to analyze the mean values and the Least significance difference (LSD) was used for mean separation at ($P < 0.05$).

Results and Discussion

Influence of *B. mucilaginosus and B. lichenformis* on Soil pH

The soil pH as influenced by *B. mucilaginosus* and *B. lichenformis* is presented in Table 1. The result shows that there was an influence on soil pH compared to the control. However, this increase was significant ($p< 0.05$). Combination of Rice husk + *B. mucilaginosus* and *B. lichenformis with a mean pH* of (6.80), Rice husk alone has a mean pH of (6.69) and control has the lowest mean pH of (6.17), which are all slightly acidic.

Soil pH is a critical factor that affects the growth and survival of microorganisms, plants, and soil chemistry. In this context, rice husk, rice husk supplemented with *B. mucilaginosus* and *B. lichenformis*, increase the soil pH. Our findings contradict the Butnan and Vityakon (2023) who reported that the Rice husk addition did not significantly affect soil pH compared to the control treatment. Though, rice husk supplemented with *B. mucilaginosus* and *B. lichenformis* and rice husk alone did not significantly differ in terms of soil pH statistically (Butnan & Vityakon, 2023). Rice husk supplemented with *B. mucilaginosus* and *B. lichenformis* are suitable for maintaining a neutral soil pH level in tropical paddy soils (Widowati & Sukristyonubowo, 2019).

The pH level of soil is a factor that affects the growth and survival of microorganisms, including *Bacillus species*. While both bacteria can adapt to a range of soil pH levels, their roles in soil may vary depending on the pH conditions (Fernández-Calviño *et al*., 2011). Acidic soils: In acidic soils with a pH below 6.0, the activity of Bacillus species may be limited due to the low availability of nutrients such as phosphorus and iron. However, other species have been found to thrive in acidic soils and has been shown to promote plant growth by producing siderophores, which increase the availability of iron for plants (Setiawati *et al*., 2022). Neutral soils: In neutral soils with a pH between 6.0 and 7.5, both Bacillus species are active and play important roles in soil health. They areinvolved in nitrogen fixation, biocontrol, promotes plant growth through siderophore production and nutrient cycling (Umar & Mazhar, 2021). Alkaline soils: In alkaline soils with a pH above 7.5, the activity of both species may be reduced due to the high pH level, which can affect the availability of nutrients and the activity of enzymes involved in biochemical processes. However, both bacteria have been found to adapt to alkaline conditions by producing proteins that protect them from the high pH environment (Shen *et al*., 2019).

Table 1**.** Influence of *B. mucilaginosus* and *B. lichenformis* on Soil pH

Treatment	**Soil pH**
Control	6.17^{b}
Rice husk	6.69^{a}
Rice husk + *B. mucilaginosus* and *B. lichenformis*	6.80^{a}
SE±	0.07
P. Value	0.03
Significance	*

*Mean in a column followed by similar letter (s) are not significantly different at 5% level of significance using least significant difference (LSD). * = Significant, SE± = Standard Error.*

Influence of *B. mucilaginosus and B. lichenformis* on Soil Available Phosphorus

The soil available phosphorus as influence by the treatment is presented in Table 2. The results show that there was an increase on soil available phosphorus at different treatment compared to the control. However, this increase was significant ($P \leq 0.05$). Rice husk +

B. mucilaginosus and *B. lichenformis* recorded the highest soil available phosphorus with a mean of (0.60 g/kg) which is high, followed by Rice husk with a mean of (0.52 g/kg) which is also high and control has the lowest mean (0.28 g/kg), which is medium according to Esu. This increase was attributed to the phosphate solubilizing properties of these bacteria, which increased the availability of phosphorus in soil for plant uptake (Liu et al., 2021). Rice husk supplemented with *B. mucilaginosus and B. lichenformis* had a positive effect on soil available P in tropical paddy soil, making it a promising amendment for sustainable agriculture practices that require high phosphorus inputs (Ong'injo *et al.*, 2023).

Table: 2. Influence of *B. mucilaginosus* and *B. lichenformis* on Soil Available Phosphorus

Treatment	**Available Phosphorus (g/kg)**
Control	0.28[c]
Rice husk	0.52[b]
Rice husk + *B. mucilaginosus* and *B. lichenformis*	0.62[a]
SE±	0.04
P. Value	0.01
Significance	*

*Mean in a column followed by similar letter (s) are not significantly different at 5% level of significance using least significant difference (LSD). * = Significant, SE± = Standard error.*

Conclusion

This study aimed to investigate the impact of *B. mucilaginosus* and *B. lichenformis* on the soil available phosphorus, and soil pH amended with rice husk. The experiment was conducted at Usmanu Danfodio University Teaching and Research Fadama Farm Kwalkwalawa, in a Completely Randomized Block Design with three treatments: Control (no amendment), Rice husk alone, Rice husk with *B. mucilaginosus* and *B. lichenformis*. The results showed that both Bacillus species significantly increased available phosphorus and soil pH, indicating their acidifying effect. The highest phosphorus availability and pH were observed in the treatment with rice husk and *B. mucilaginosus* and *B. lichenformis*. The study suggests that the application of *B. mucilaginosus* and *B. lichenformis* in combination with rice husk amendment can enhance the phosphorous availability and pH in soil, which may have potential benefits for crop production. Nevertheless, *B. mucilaginosus* and *B. lichenformis* have shown potential as decomposers to enhance organic residue decomposition and nutrient cycling. These findings highlight the potential of integrating rice husk and microbial inoculants for farmers and other relevant stakeholders to improve soil fertility in semi-arid agricultural systems. Further researches are recommended to explore long-term effects and optimize application strategies for broader adoption in Sub-Saharan Africa.

References:

Aihonsu, J., & Adesimi, A. (2006). Comparative economic competitiveness in rice production in

Ogun State, Nigeria. *Moor Journal of Agricultural Research*, *5*(2), 7-11.

AL-qasy, H. H. H., & Al-Shammari, M. Z. F. (2022). Efficacy of NPK Nano Fertilizer and Bio-bacterial Fertilizer on Weight and Chlorophyll of Two Cultivars of Fenugreek (Trigonella *Foenum-graceum* L.). *International Journal of Health Sciences*, (II), 11525-11537.

Amadou, I., Faucon, M. P., & Houben, D. (2022). Role of soil minerals on organic phosphorus availability and phosphorus uptake by plants. *Geoderma*, 4(28), 116-125.

Bray, R.H. and Kurtz, L.T. (1945). Determination of total organic and Available Forms of Phosphorus in soil. *Soil Science*.59:39-45

Butnan, S., & Vityakon, P. (2023). Lengths of Time of Rice Husk Biochar Incorporation before Planting Affect Soil Properties and Rice Yield. *Agronomy*, *13*(6), 144-145.

Chen, M., Luo, X., Jiang, L., Dong, R., Siddique, K., & He, J. (2023). Legume crops use a phosphorus-mobilising strategy to adapt to low plant-available phosphorus in acidic soil in southwest China. *Plant, Soil and Environment*, *69*(10), 471–479.

Chen, Y., Li, S., Liu, N., He, H., Cao, X., Lv, C. & Dai, J. (2021). Effects of different types of microbial inoculants on available nitrogen and phosphorus, soil microbial community, and wheat growth in high-P soil. *Environmental Science and Pollution Research*, 28, 23036-23047.

Delfim, J., Schoebitz, M., Paulino, L., Hirzel, J., & Zagal, E. (2018). Phosphorus Availability in Wheat, in Volcanic Soils Inoculated with Phosphate-Solubilizing Bacillus thuringiensis. *Sustainability*, *10*(2), 144-146.

Ebe, S. (2020). Rice husk biochar with beneficial microbes: A promising agricultural inoculant and soil ameliorant. *Research Outreach*, *113*, 50–53.

Fernández-Calviño, D., Rousk, J., Brookes, P. C., & Bååth, E. (2011). Bacterial pH-optima for growth track soil pH, but are higher than expected at low pH. *Soil Biology and Biochemistry*, *43*(7), 1569–1575.

Fu, D., Wu, X., Duan, C., Zhao, L., & Li, B. (2020). Different life-form plants exert different rhizosphere effects on phosphorus biogeochemistry in subtropical mountainous soils with low and high phosphorus content. *Soil and Tillage Research*, *199*, 104-116.

Gill, K. S., & Jalota, S. K. (2021). Previous and Current Crop Effects on Early-Season Root Growth and Growing Season's Soil Moisture Under Dryland Agriculture in Temperate Climate. *Journal of Agricultural Science*, *13*(5), 50-62.

He, Q., Sun, Y., Yi, M., & Huang, H. (2023). How to promote agricultural enterprises to reduce the use of pesticides and fertilizers? An evolutionary game approach. *Frontiers in Sustainable Food Systems*, *7*, 40-45

Hou, E., Tan, X., Heenan, M., & Wen, D. (2018). A global dataset of plant available and unavailable phosphorus in natural soils derived by Hedley method. *Scientific Data*, *5*(1), 14-19

Hussain, A. (2019). Combining phosphorus (P) with phosphate solubilizing bacteria (PSB) improved wheat yield and P uptake in alkaline soil. *Pure and Applied Biology*, *8*(2), 25-33.

Kong, F., & Lu, S. (2022). Soil Inorganic Amendment Produces Safe Rice by Reducing the Transfer of Cd from Rice Root to Grain and Increasing Key

Amino Acids in Brown Rice. *SSRN Electronic Journal*, *54(9)*, 117-124.

Kovar, J., & Cantarella, H. (2019). Measuring Crop-Available Phosphorus. *Better Crops With Plant Food*, *103*(1), 13–16.

Li, H., Zhong, Y., Huang, H., Tan, Z., Sun, Y., & Liu, H. (2020). Simultaneous nitrogen and phosphorus removal by interactions between phosphate accumulating organisms (PAOs) and denitrifsying phosphate accumulating organisms (DPAOs) in a sequencing batch reactor. *Science of the Total Environment*, *744*, 140-152.

Li, M., Li, Q., Yun, J., Yang, X., Wang, X., Lian, B., & Lu, C. (2017). Bio-organic-mineral fertilizer can improve soil quality and promote the growth and quality of water spinach. *Canadian Journal of Soil Science*, 88, 248-261.

Linam, F., Limmer, M. A., Ebling, A. M., & Seyfferth, A. L. (2023). Rice husk and husk biochar soil amendments store soil carbon while water management controls dissolved organic matter chemistry in well-weathered soil. *Journal of Environmental Management*, *339*, 117-136.

Liu, X., Chen, C., Wang, J., Zou, S., & Long, X. (2021). Phosphorus solubilizing bacteria Bacillus thuringiensis and Pantoea ananatis simultaneously promote soil inorganic phosphate dissolution and soil Pb immobilization. *Rhizosphere*, *20*, 100-148.

Mishra, A., Taing, K., Hall, M. W., & Shinogi, Y. (2017). Effects of Rice Husk and Rice Husk Charcoal on Soil Physicochemical Properties, Rice Growth and Yield. *Agricultural Sciences*, *8*(9), 1014–1032.

Moro, H., Park, H. D., & Kunito, T. (2021). Organic Phosphorus Substantially Contributes to Crop Plant Nutrition in Soils with Low Phosphorus Availability. *Agronomy*, *11*(5), 903-911.

Mshari, A., Hussein, A. F., & Dawood, N. J. (2019). Ability of Creative of bioformulations Using Bacillus Subtilis for Biological Control of Some Plant Disease Fungi. *Journal of Research on the Lepidoptera*, *50*(4), 17–24.

Ong'injo, R. O., Kengara, F. O., & Shikanga, E. (2023). Potential of biochar amendment as phosphorus source in tropical paddy soil. *Applied Chemical Engineering*, *6*(3), 34-41.

Oppong Danso, E., Monnie, F., Abenney-Mickson, S., Arthur, E., Benjamin Sabi, E., & Neumann Andersen, M. (2021). Does Biochar Particle Size, Application Rate and Irrigation Regime Interact to Affect Soil Water Holding Capacity, Maize Growth and Nutrient Uptake? *Journal of Soil Science and Plant Nutrition*, *21*(4), 3180–3193.

Richts, B., Rosenberg, J., & Commichau, F. M. (2019). A Survey of Pyridoxal 5′-Phosphate-Dependent Proteins in the Gram-Positive Model Bacterium Bacillus subtilis. *Frontiers in Molecular Biosciences*, *6*, 112-117.

Saadouli, I., Mosbah, A., Ferjani, R., Stathopoulou, P., Galiatsatos, I., Asimakis, E., Marasco, R., Daffonchio, D., Tsiamis, G., & Ouzari, H. I. (2021). The Impact of the Inoculation of Phosphate-Solubilizing Bacteria Pantoea agglomerans on Phosphorus Availability and Bacterial Community Dynamics of a Semi-Arid Soil. *Microorganisms*, *9*(8), 16-31.

Selzer, T., & Schubert, S. (2021). Nutrient uptake of catch crops under non-limiting growth conditions. *Journal of Plant Nutrition and Soil Science*, *184*(6), 709–722.

Setiawati, T. C., Erwin, D., Mandala, M., & Hidayatulah, A. (2022). Use of Bacillus as a Plant Growth-Promoting Rhizobacteria to Improve Phosphate and Potassium Availability in Acidic and Saline Soils. *KnE Life Sciences*, 18, 35-42.

Shen, C., Shi, Y., Fan, K., He, J. S., Adams, J. M., Ge, Y., & Chu, H. (2019). Soil pH dominates elevational diversity pattern for bacteria in high elevation alkaline soils on the Tibetan Plateau. *FEMS Microbiology Ecology*, *95*(2), 328-334.

Singh, S. K., Singh, M., & Singh, A. K. (Eds.). (2014). Nitrogen fixation by Bacillus species: A review [Review]. *Journal of Applied Microbiology*, 8, 73-77.

Skrzypczak, D., Gil, F., Izydorczyk, G., Mikula, K., Gersz, A., Hoppe, V., Chojnacka, K., & Witek-Krowiak, A. (2022). Innovative bio-waste-based multilayer hydrogel fertilizers as a new solution for precision agriculture. *Journal of Environmental Management*, *321*, 116-122.

Thomas, S., Mathew, L., & Rishad, K. (2018). Isolation and molecular identification of phosphate solubilizing bacteria, Bacillus licheniformis UBPSB-07 capable of enhancing seed germination in *Vigna radiata* L. *Phytomorphology*, 68(1&2), 13-18.

Umar, J., & Mazhar, S. (2021). Comprehensive overview on Bacillus subtilis antibacterial metabolites production. *Pakistan BioMedical Journal*, *4*(1), 234-239.

Vermeiren, C., Kerckhof, P., Reheul, D., & Smolders, E. (2021). Increasing soil organic carbon content can enhance the long-term availability of phosphorus in agricultural soils. *European Journal of Soil Science*, *73*(1), 335-342.

Widowati, L. R., & Sukristyonubowo. (2019). Dynamics of pH, Ferrum and Mangan, and Phosphorus on Newly Opened Paddy Soil having High Soil Organic Matter on Rice Growth. *Journal of tropical soils*, *17*(1), 11-19.

Wissuwa, M., Gonzalez, D., & Watts-Williams, S. J. (2020). The contribution of plant traits and soil microbes to phosphorus uptake from low-phosphorus soil in upland rice varieties. *Plant and Soil*, *448*(1–2), 523–537.

Xiang, Y., Liu, Y., Gong, M., Tong, Y., Liu, Y., Zhao, G., & Yang, J. (2023). Preparation of Novel Biodegradable Polymer Slow-Release Fertilizers to Improve Nutrient Release Performance and Soil Phosphorus Availability. *Polymers*, *15*(10), 22-42.

Yu, X., Keitel, C., & Dijkstra, F. A. (2023). Ameliorating soil acidity with calcium carbonate and calcium hydroxide: effects on carbon, nitrogen, and phosphorus dynamics. *Journal of Soil Science and Plant Nutrition*, *23*(4), 5270–5278.