



Advances in biology through agronomy, aquaculture, coastal and environmental sciences

— Volume II —

Leandri Argentel-Martínez
Ofelda Peñuelas-Rubio
Joe Luis Arias-Moscoso
Editors

Leandris Argentel-Martínez
Ofelda Peñuelas-Rubio
Joe Luis Arias-Moscoso
Editors

**Advances in biology through
agronomy, aquaculture, coastal and
environmental sciences**
Volume II



Pantanal Editora

2026

Copyright © Pantanal Editora

Editor-in-Chief: Dr. Alan Mario Zuffo

Executive Editors: Dr. Jorge González Aguilera and Dr. Bruno Rodrigues de Oliveira

Design: The editor. **Design and art:** The editor. **Cover and back cover images:** Editor(s). **Review:** Author(s), organizer(s), and editor(s).

Editorial Board

Academic degree and name

Prof. Dr. Adaylson Wagner Sousa de Vasconcelos
Profa. MSc. Adriana Flávia Neu
Profa. Dra. Albys Ferrer Dubois
Prof. Dr. Antonio Gasparetto Júnior
Profa. MSc. Aris Verdecia Peña
Profa. Arisleidis Chapman Verdecia
Prof. Dr. Arinaldo Pereira da Silva
Prof. Dr. Bruno Gomes de Araújo
Prof. Dr. Caio Cesar Enside de Abreu
Prof. Dr. Carlos Nick
Prof. Dr. Claudio Silveira Maia
Prof. Dr. Cleberton Correia Santos
Prof. Dr. Cristiano Pereira da Silva
Profa. Ma. Dayse Rodrigues dos Santos
Prof. MSc. David Chacon Alvarez
Prof. Dr. Denis Silva Nogueira
Profa. Dra. Denise Silva Nogueira
Profa. Dra. Dennyura Oliveira Galvão
Prof. Dr. Elias Rocha Gonçalves
Prof. Me. Ernane Rosa Martins
Prof. Dr. Fábio Steiner
Prof. Dr. Fabiano dos Santos Souza
Prof. Dr. Gabriel Andres Tafur Gomez
Prof. Dr. Hebert Hernán Soto Gonzáles
Prof. Dr. Hudson do Vale de Oliveira
Prof. MSc. Javier Revilla Armesto
Prof. MSc. João Camilo Sevilla
Prof. Dr. José Luis Soto Gonzales
Prof. Dr. Julio Cezar Uzinski
Prof. MSc. Lucas R. Oliveira
Prof. Dr. Luciano Façanha Marques
Profa. Dra. Keyla Christina Almeida Portela
Prof. Dr. Leandris Argentele-Martínez
Profa. MSc. Lidiene Jaqueline de Souza Costa Marchesan
Prof. Dr. Marco Aurélio Kistemann
Prof. MSc. Marcos Pisarski Júnior
Prof. Dr. Marcos Pereira dos Santos
Prof. Dr. Mario Rodrigo Esparza Mantilla
Profa. MSc. Mary Jose Almeida Pereira
Profa. MSc. Núbia Flávia Oliveira Mendes
Profa. MSc. Nila Luciana Vilhena Madureira
Profa. Dra. Patrícia Maurer
Profa. Dra. Queila Pahim da Silva
Prof. Dr. Rafael Chapman Auty
Prof. Dr. Rafael Felipe Ratke
Prof. Dr. Raphael Reis da Silva
Prof. Dr. Renato Jaqueto Goes
Prof. Dr. Ricardo Alves de Araújo (*In Memoriam*)
Profa. Dra. Sylvana Karla da Silva de Lemos Santos
Prof. Dr. Tayronne de Almeida Rodrigues
Prof. Dr. Ugur Azizoglu
Prof. Dr. Wéverson Lima Fonseca
Prof. MSc. Wesclen Vilar Nogueira
Profa. Dra. Yilan Fung Boix
Prof. Dr. Willian Douglas Guilherme

Institution

OAB/PB
Mun. Faxinal Soturno e Tupanciretã
UO (Cuba)
IF SUDESTE MG
Facultad de Medicina (Cuba)
ISCM (Cuba)
UFESSPA
UEA
UNEMAT
UFV
AJES
UFGD
UEMS
IFPA
UNICENTRO
IFMT
UFMG
URCA
ISEPAM-FAETEC
IFG
UEMS
UFF
(Colômbia)
UNAM (Peru)
IFRR
UCG (México)
Rede Municipal de Niterói (RJ)
UNMSM (Peru)
UFMT
SED Mato Grosso do Sul
UEMA
IFPR
Tec-NM (México)
Consultório em Santa Maria
UFJF
UEG
FAQ
UNAM (Peru)
SEDUC/PA
IFB
IFPA
UNIPAMPA
IFB
UO (Cuba)
UFMS
UFPI
UFG
UEMA
IFB
Sec. Mun. de Educação, Cultura e Tecnologia de Araripe
Universidade Kayseri, Türkiye
UFPI
FURG
UO (Cuba)
UFT

Scientific and Technical Council
- Esp. Joacir Mário Zuffo Júnior
- Esp. Maurício Amormino Júnior
- Lda. Rosalina Eufrausino Lustosa Zuffo

Catalog sheet

Cataloging in publication
Prepared by a Librarian Janaina Ramos – CRB-8/9166

A244

Advances in biology through agronomy, aquaculture, coastal and environmental sciences - Volume II /
Editors Leandris Argente-Martínez, Ofelda Peñuelas-Rubio, Joe Luis Arias-Moscoso. – Nova
Xavantina-MT: Pantanal, 2026.
362p. ; il.

Book in PDF format

ISBN 978-65-85756-79-2

DOI <https://doi.org/10.46420/9786585756792>

1. Biology. 2. Agronomy. 3. Aquaculture. 4. Environmental sciences. I. Argente-Martínez, Leandris
(Editor). II. Peñuelas-Rubio, Ofelda (Editor). III. Arias-Moscoso, Joe Luis (Editor). IV. Title.

CDD 570

Index to systematic catalog

I. Biology



Our ebooks are free and publicly accessible, downloadable, and shareable, but we ask that proper credit be given to Pantanal Editora, as well as to the organizers and authors. However, the use of ebooks for commercial purposes is not permitted without the express authorization of the authors and the agreement of Pantanal Editora.

Pantanal Editora

Rua Abaete, 83, Sala B, Centro. CEP: 78690-000.
Nova Xavantina – Mato Grosso – Brasil.
Telefone (66) 99682-4165 (Whatsapp).
<https://www.editorapantanal.com.br>
contato@editorapantanal.com.br

Advances in Biology through Agronomy, Aquaculture, Coastal and Environmental Sciences, Volume II, is an e-book that continues the work of the first version (<https://editorapantanal.com.br/ebooks/2023/advances-in-biology-through-agronomy-aquaculture-coastal-and-environmental-sciences/ebook.pdf>), published in 2023 by Leandris Argente-Martínez and Ofelda Peñuelas-Rubio.

Our e-book compiles 25 manuscripts that present scientific results and reviews based on biological aspects. All of them contribute to explaining the responses of living organisms to agricultural, aquaculture, and coastal ecosystems, as well as those facing fragility or threat of climate change. This e-book was edited by Leandris Argente-Martínez, Ofelda Peñuelas-Rubio, and Joe Luis Arias-Moscote, members of the Consolidated Academic Group ITVAYA-CA-3.

We appreciate the contribution of all authors for their careful attention to the editorial committee's recommendations. The review process was double-blind and conducted by internationally renowned researchers.

Special thanks to the members of the BioSecuraNet International Network for Biotechnology and Innovative Strategies for Global Food Security at the National Technological Institute of Mexico.

The Editors

Prologue	4
Agronomy	
Chapter 1	9
The reduction in chemical fertilization combined with PGPM under a controlled deficit irrigation system for maize	
Chapter 2	22
Effects of sowing date and size on the physical and physiological quality of bread wheat seeds in southern Sonora, Mexico	
Chapter 3	35
Morphophysiological response and yield of tomato (<i>Solanum lycopersicum</i> L.) to growth regulators and glutamic acid	
Chapter 4	49
Influence of benzoxazinoid metabolites in maize roots interacting with diverse microbes	
Chapter 5	64
Comparison of RGB spectrum vegetation indices to estimate agronomic variables in wheat and oats	
Chapter 6	74
Alleviation of saline stress in maize and peanut plants induced by <i>Bacillus aryabhattai</i> strain CMAA 1363	
Chapter 7	92
Bacterial consortia as a sustainable strategy for disease management and productivity improvement in maize	
Chapter 8	109
Agronomic management for oat seed production in the Bajío region, Mexico	
Chapter 9	125
Risk factors in loading and unloading operations of agricultural products in land transport units at a company in Veracruz, Mexico	
Chapter 10	145
Physicochemical characterization of four varieties of durum wheat (<i>Triticum durum</i> Desf.) under full irrigation and reduced irrigation conditions	
Chapter 11	161
Antifungal activity of edible chitosan coatings and <i>Coriandrum sativum</i> L. essential oil against <i>Colletotrichum gloeosporioides</i> and their application on mango fruits	
Chapter 12	175
Agricultural gypsum with micronutrients in citrus cultivation	
Chapter 13	186

Initial Agronomic Adaptation of *Stevia rebaudiana* Bertoni in the High Mountain Region of Veracruz and Sustainable Management of *Planococcus citri* Using a Neem-Based Bioinsecticide

Chapter 14 197

Evaluation of yield components of two F1 maize hybrids under controlled deficit irrigation in a moderately saline vertisol soil in Yaqui Valley, Sonora, Mexico

Aquaculture

Chapter 15 207

Effects of partially replacing fish meal with mesquite pod meal (*Prosopis juliflora*) on the growth of Nile tilapia (*Oreochromis niloticus*)

Chapter 16 220

Consumer preferences and value-added opportunities in the commercialization of *Oreochromis niloticus* in Tenosique, Tabasco, México

Chapter 17 228

Partial substitution of pechita (*Prosopis glandulosa*) and alfalfa (*Medicago sativa*) flour with commercial flour in diets for tilapia (*Oreochromis niloticus*) farming

Chapter 18 239

Hydrolysate of the alga *Spirulina* influences the proliferation, growth, and development of *Spathiphyllum uxpanapense* in vitro

Chapter 19 251

Growth of the wild juvenile common snook *Centropomus undecimalis* in captivity

Coastal Sciences

Chapter 20 260

Notes on the recreational fishing of snook (*Centropomus* spp.) in the coastal zone of Centla, Tabasco, Mexico

Chapter 21 268

Linkage among climatic variation and artisanal fisheries behavior of common snook (*Centropomus undecimalis*) in tropical Atlantic coast

Environmental Sciences

Chapter 22 277

Fungal-based arsenic bioremediation: linking enzymatic detoxification mechanisms with bioreactor engineering

Chapter 23 292

Simplified dynamic modeling for scenario analysis of the anaerobic digestion of fruit and vegetable waste

Chapter 24 303

Impact of biofertilizers on wheat (*Triticum aestivum* L.) yield in different environments of the Bajío region of Guanajuato

Chapter 25 326

Genomic Reprogramming and Epigenetic Memory: Transforming Somaclonal Variation into a Tool for Climate Resilience

Chapter 26	351
Research on the use of rhizobacteria for the biodegradation of herbicides and insecticides in agriculture and their effects on environmental protection	
Index	360
About the editors	362

Research on the use of rhizobacteria for the biodegradation of herbicides and insecticides in agriculture and their effects on environmental protection

Received: 14/04/2026

Accepted: 05/05/2026

 10.46420/9786585756792cap26

Jose Aurelio Leyva-Ponce¹ 

Leandris Argente-Martinez^{1*} 

Ofelda Peñuelas-Rubio¹ 

Catarino Perales-Segobia² 

Lorenzo Pérez-López¹ 

Jorge González Aguilera³ 

ABSTRACT

In modern agriculture worldwide, increased crop yields are associated with increased doses of chemical products, such as pesticides and herbicides, to promote better crop development, reduce competition, and decrease the number of pests that negatively affect yield. This situation leads to a significant increase in the pollutant load. Although the biodegradation and neutralization capabilities of the residual effects of chemical products have been studied, this topic is still not fully understood. While many pesticides are selective, they can damage other crops and the environment. Considering the need to protect the environment and the existence of beneficial microbiological conditions in some areas, such as semideserts, alternative biodegradation methods using these microorganisms could be explored, which would have significant economic, ecological, and environmental implications. This study aims to conduct an updated literature review of recent advances in the use of microorganisms for the bioremediation of herbicides and insecticides to gather references and establish biodegradation trials under laboratory and field conditions. Studies confirm that the use of microorganisms is feasible for the biodegradation of herbicides and insecticides; therefore, in some regions, such as Yaqui Valley, Sonora, it could become a sustainable and ecologically viable option for environmental protection.

Keywords: beneficial microbiological conditions, sustainable, chemical products, pesticides

¹ Tecnológico Nacional de México / Instituto Tecnológico del Valle del Yaqui, Bâcum, Sonora, México.

² Tecnológico Nacional de México/Instituto Tecnológico El Llano Aguascalientes (ITEL), México.

³ Department of Crop Science, State University of Mato Grosso do Sul, Cassilândia 79540-000, MS, Brazil.

*Corresponding author: oleinismora@gmail.com

INTRODUCTION

A wide variety of physical and chemical methods exist for treating contaminated soils and aquifers, but many of these treatments do not destroy hazardous compounds but rather transfer them from one phase to another. Therefore, biological treatment, in which these hazardous compounds are transformed into simpler compounds, is a significant challenge. These methods offer the advantages of operating at ambient temperature and pressure, reducing capital and operating costs. However, a limitation of biotreatment systems is the toxic potential of xenobiotic agents.

In practice, this means that great care must be taken with the microorganisms used, as they can be inhibited or killed by the toxic effects of organic contaminants (Beshay et al., 2002). For biodegradation, the pesticide can ideally serve as the sole source of carbon and energy for microorganisms, including the synthesis of the appropriate enzymes for its transformation, providing an important mechanism in the degradation of xenobiotic compounds in the environment (Murugesan et al., 2010).

Pesticides (herbicides, fungicides, and insecticides) are widely used in agriculture and industry worldwide because of their high activity. More than 55% of the land used for agricultural production in developing countries uses approximately 26% of the total pesticides produced globally.

However, the rate of increase in pesticide use in developing countries is considerably greater than that in developed countries. Pesticides are necessary to protect crops, as losses can constitute approximately 45% of total global food production. Although several classes of pesticides exist, pyrethroids are among the most important because they are highly effective even at very low concentrations. These are commonly used against flies, mosquitoes, and aphids.

The extensive and incorrect use of chemical products leads to greater risks to the health of plants, animals, and the human population. One of the serious problems with pesticides is their high persistence, which increases their toxicity and carcinogenicity (Dalvie et al., 2003; Holmes et al., 2008; Murugesan et al., 2010). In Mexico, the cultivated agricultural area over the last 20 years has totalled 20 million hectares, with rainfed agriculture being the most prevalent system. This area later decreased to 15.5 million hectares, while the area of irrigated agriculture remained at 5 hectares during this period; in total, this represents 75% of the planted area in the country.

The main problems for grain and vegetable crops have been the different types of diseases, pests, and weeds that damage everything from the seed to the plant and the fruit. These problems have been mitigated through the application of pesticides.

The use of pesticides, which are primarily applied in agricultural activities, has caused environmental damage. Soil contamination can lead to a loss of fertility, which can also affect beneficial microbial populations. These beneficial microorganisms can reach the air through the volatilization of

compounds and their dispersion into the atmosphere and surface water and groundwater through leaching and infiltration (Dhananjayan et al., 2019).

The role of bacteria in the biodegradation and transformation of pesticides in the soil varies and depends on the availability, mobility, and toxicity of the pesticide and the physicochemical properties of the soil and the pesticide, among other environmental factors (Racke; Coats, 1990). Among the microbial groups reported as pesticide-degrading organisms are many heterotrophic bacteria that are used as substrates, either by metabolizing the molecules or using them as nutrients and energy sources. This group of bacteria includes *Azotobacter* spp., *Pseudomonas* spp., *Agrobacterium* spp., *Bacillus* spp., *Clostridium* spp., and *Flavobacterium* spp., among others (Madigan et al., 2004).

Use of Pesticides

Pesticides are chemical compounds used to eliminate pests. They are chemical or biological agents that weaken, disable, and kill pests. Pesticides can be divided into several groups according to the type of pest they target: insecticides, herbicides, rodenticides, bactericides, fungicides, and larvicides. The literature mentions that during the 19th and 20th centuries, plant extracts, specifically pyrethrins, were used as insecticides, fungicides, and herbicides. The increased use of pesticides occurred with the advent of synthetic chemistry during the 1930s. During this period, inorganic chemicals such as arsenic and sulfur compounds were applied for crop protection. Arsenic poison was deadly to insects, while sulfur was used as a fungicide. At the beginning of World War II, numerous pesticides were synthesized, primarily organic chemicals such as dichlorodiphenyltrichloroethane (DDT), aldrin, and dieldrin, which were used as insecticides, while 2-methyl-4-chlorophenoxyacetic acid (MCPA) and 2,4-dichlorophenoxyacetic acid (2,4-D) were used as herbicides (Matthews, 2018).

Degree of Pesticide Contamination and its Effect on the Environment

Pesticides are intended to prevent, eliminate, and control harmful pests, which can be detrimental to the environment and human health. Their indiscriminate use can generate high concentrations of pollutants in the environment. Over the years, the World Health Organization has classified pesticides and reported their toxicity and effects on human health. Currently, several pesticides are banned in some countries because of their high toxicity. However, their production and use continue, especially in developing countries (Tudi et al., 2021).

Pesticides persist in the environment and can bioaccumulate and contaminate the food chain, affecting human health and the environment as a whole. Pesticides tend to retain their molecular integrity and their chemical, physical, and functional characteristics for a certain period after their release into the soil (Pérez-Lucas, et al., 2020).

Process and Mechanism of Bacterial Biodegradation of Pesticides

Over the years, several bacterial strains capable of degrading the pesticides present in soils have been identified. Each bacterium possesses a specificity that makes it particularly suitable for a particular degradation process. Operating conditions, such as temperature, pH, water content, and the types of contaminants, affect the adaptation, development, and function of a bacterial strain. Furthermore, metabolites can form during the degradation process and cause additional environmental problems, as they can be more difficult to remove than the original compound, which should be considered a disadvantage. For example, chlorpyrifos, an organophosphate used as an insecticide, is hydrolyzed by microorganisms, and the main degradation product is 3,5,6-trichloro-2-pyridinol (TCP). TCP is more water soluble than chlorpyrifos and causes widespread contamination in soils and aquatic environments. Few microorganisms can degrade pesticides and their metabolites, and among them, the bacterium *Ochrobactrum* sp. JAS2 is capable of hydrolyzing both compounds (Abraham & Silambarasan, 2016). In many cases, degradation is easier when a bacterial consortium is used than when an isolated pure culture is used (Doolotkeldieva et al., 2021; Jariyal et al., 2018). In nature, bacteria coexist and depend on each other for their viability. In pesticide degradation metabolic pathways, each bacterium can generate metabolites that can be used as a substrate by others.

During biodegradation processes, pesticides are transformed into degradation products or completely mineralized by the action of microorganisms, which use polluting compounds as nutrients for their metabolic reactions. Enzymes such as hydrolases, peroxidases, and oxygenases play key roles in biotransformation mechanisms, influencing and catalyzing biochemical reactions.

The pesticide degradation process can be divided into three phases, which can be summarized as follows:

Phase 1: Pesticides are transformed into more water-soluble and less toxic products through oxidation, reduction, or hydrolysis reactions.

Phase 2: The products of Phase 1 are converted into sugars and amino acids, which have greater water solubility and lower toxicity.

Phase 3: Conversion of the metabolites from Phase 2 into less toxic secondary conjugates. The microorganisms involved in the degradation process are bacteria or fungi, which can produce intracellular or extracellular enzymes (Khajezadeh et al., 2020).

In many cases, biodegradation is easier when a bacterial consortium is used than when an isolated pure culture is used. In nature, bacteria coexist and depend on each other for their viability. In pesticide degradation metabolic pathways, each bacterium can produce metabolites that can be used as a substrate by others (Doolotkeldieva et al., 2026; Jariyal et al., 2018). Research has reported some organophosphate-degrading microorganisms, such as certain species of the genus *Lactobacillus*, and some fungi, such as

Hypholoma fasciculare, *Coriolus versicolor*, and *Phanerochaete chrysosporium*. and some bacteria, such as *Serratia liquefaciens*, *Serratia plymuthica*, *Pseudomonas putida* and *Pseudomonas radiora* (Kosimov et al., 2015).

National and international research on pesticide biodegradation

In Mexico, in the Yaqui Valley, Sonora, experiments were conducted in an area with a 15–25-year history of pesticide contamination and handling. Carrillo et al. (2004) isolated mixed bacterial cultures from contaminated water, soil, and sediment samples. This culture consisted of gram-negative bacilli belonging to the genera *Pseudomonas*, *Neisseria*, *Moraxella*, and *Acinetobacter*. It was evaluated in the presence of DDT (133 ppm) as the sole carbon source and degraded with 43% efficiency within 80 hours. Similarly, the concentrations of the metabolites DDD and DDE, impurities of commercial DDT, were completely degraded without any observed increase.

Another case study using bacteria to degrade contaminants was conducted by Mendoza et al. (2011). In this study, permethrin and cypermethrin were degraded at concentrations of 50 and 100 mg/L, respectively, over a period of 5 to 20 days using strains of *Pseudomonas putida*, *Pseudomonas mendocina*, *Chromobacterium violaceum*, and *Burkholderia cepacia* in batch reactors. These bacteria were isolated from hydrocarbon-contaminated soils in the municipality of Acatzingo, Puebla. This bacterial consortium achieved a degradation efficiency of more than 90% at a concentration of 50 mg/L, and at 100 mg/L, a degradation efficiency of 89% or higher was obtained. At both concentrations, the efficiency of permethrin degradation was greater than that of cypermethrin degradation. Despite these differences, the results demonstrate that these bacteria can be used individually or in consortia for the biodegradation of pyrethroid pesticides.

Degradation studies using bacteria were conducted at the Autonomous University of the State of Morelos. A bacterial consortium was isolated from agriculturally managed soils. This consortium contained strains identified as *Stenotrophomonas maltophilia*, *Proteus vulgaris*, *Vibrio metschnikovii*, *Serratia ficaria*, *Serratia* spp., and *Yersinia enterocolitica*. The experiments evaluated the ability of the bacteria to degrade tetrachlorvinphos (phosphoric acid, 2-chloro-1-(2,4,5-trichlorophenyl) ethenyldimethyl ester) as the sole carbon source. The consortium demonstrated the feasibility of using the product in the bioremediation of soils contaminated with this type of pesticide. The hydrolyzed compounds were analyzed using gas chromatography coupled with mass spectrometry (Ortiz; Sánchez, 2010).

Yah (2018) analyzed the degradation level of 2,4-dichlorophenoxyacetic acid by native bacteria from agricultural soils in the community of San Víctor in Corozal, Belize, Mexico. The results revealed that the degradation percentage by strains B01 and B03 was 32.31% and 29.87%, respectively, after 6 days.

Ortiz-Hernández et al., (2018). Strategies for biodegradation and bioremediation of pesticides in the environment. Strategies for bioremediation of organic and inorganic pollutants, 95-115. aimed to evaluate the effectiveness of atrazine degradation by bacteria isolated from agricultural soils. In this research, the herbicide GESAPRIM granular 90 WG was used. containing 90% atrazine. Selection of atrazine-degrading consortia was performed, along with rRNA gene amplification and molecular analysis. The results showed that the MIG-AI consortium exhibited the best performance, with a specific growth rate of 0.31 h^{-1} , solubilizing atrazine in 2 days and generating clearing zones in 4 days in liquid and solid media, respectively. Furthermore, 16S rRNA gene analysis revealed that the *Stenotrophomonas maltophilia* MIG-AI/2 strain was able to degrade atrazine. Finally, the selected consortia generated clearing zones after 6 days.

Kamika and Momba (2013) conducted a study in Witbank, Mpumalanga, South Africa, where they collected samples of industrial wastewater from an area with a mining history. These water samples underwent various characterization analyses (BOD, pH, and dissolved oxygen). Additionally, the attenuation efficiency of the bacteria *Pseudomonas putida*, *Bacillus licheniformis*, and *Peranema* spp. in water contaminated with heavy metals was evaluated. The results revealed the following removal rates for *Pseudomonas putida* (Co71%, Ni-51%, Mn-45%, V-83%, Pb-96%, Ti-100%, and Cu-49%), *Bacillus licheniformis* (Al-23% and Zn-53%), and *Peranema* spp. (Cd-42%), with *Pseudomonas putida* and *Bacillus licheniformis* being the most efficient strains.

Benitez et al. (2009) conducted research with various pesticides and reported that the toxicity of herbicides was moderate, above that of insecticides and below that of fungicides, indicating that herbicides were the most toxic to *Bacillus subtilis*. Furthermore, a difference was observed between Furadan and the herbicide Tordon 101. Furadan was described as having no significant toxicity to bacteria, whereas among its compounds, Tordon 101, which contains 2,4-D, was the most toxic herbicide reported (Benitez et al., 2009). These findings coincide with the results obtained in the present study, in which the herbicide Esteron (2,4-D) resulted in greater bacterial inhibition than the insecticides and acaricides Malathion and Furadan (Carbofuran).

This summary table presents the most relevant research and authors during the period 2024–2026 on the use of plant growth-promoting rhizobacteria (PGPR) for the biodegradation of agrochemicals and environmental protection.

In the past two years, research has shifted from studying individual bacteria to focusing on microbial consortia and gene editing (CRISPR) to accelerate soil biodegradation.

CONCLUSIONS

The bioremediation of agricultural soil for pesticide removal can be carried out by exploiting specific or native microorganisms (bacteria and fungi) or through enzymatic degradation. While

numerous studies on soil bioremediation at the laboratory level exist in the literature, little information is available on real-world, large-scale activities. unfortunately, this is due mainly to the lack of cooperation between research laboratories, local authorities that mandate specific soil cleanup measures, and companies involved in the bioremediation of pesticide-contaminated soils.

The use of soil microorganisms and their beneficial interactions with plants and the ecosystem is a promising strategy for achieving sustainable agriculture, especially given the high frequency of glyphosate detection in agricultural soils. It is necessary to gather and organize scientific references related to the microbial bioremediation of the main organophosphate pesticides to facilitate access. Given the significant increase in the use of these agrochemicals in recent years, there has also been a growing interest in understanding how they act in arable soils and how pesticide residues can be eliminated through bioremediation.

The success or failure of bioremediation depends on several factors, such as the competitive ability of the microorganisms, bioavailability, organophosphate concentration, moisture, pH, soil temperature, soil type, the presence or absence of nutrient supplements, and the inoculum concentration.

Microbial consortia have demonstrated greater potential for pesticide degradation than individual populations do since a consortium's effectiveness is the sum of its components. indeed, compatible physiological and ecological relationships between individuals allow them to coexist and develop complex functions that guarantee the metabolism of substrates that are difficult to assimilate in higher percentages for individual populations.

ACKNOWLEDGEMENTS

To the BioSecuraNet International Network—International Network for Biotechnology and Innovative Strategies for Global Food Security.

REFERENCES

- Abraham, J., & Silambarasan, S. (2016). Biodegradation of chlorpyrifos and its hydrolysis product 3, 5, 6-trichloro-2-pyridinol using a novel bacterium *Ochrobactrum* sp. JAS2: a proposal of its metabolic pathway. Pesticide biochemistry and physiology, 126, 13-21. <https://doi.org/10.1016/j.pestbp.2015.07.001>
- Benitez, N., Vivas, D. H., Rosero, E. D. (2009). Toxicidad de los principales plaguicidas utilizados en el municipio de Popayán, usando *Bacillus subtilis*. Facultad de Ciencias Agropecuarias, 7(1),15-22. http://www.scielo.org.co/scielo.php?pid=S1692-35612009000100003&script=sci_arttext
- Beshay, U.; Desouky, Abd-El-Haleem; Hassan, Moawad; Sahar, Z. (2002). Phenol biodegradation by free and immobilized *Acinetobacter*. Biotechnology Letters: 24, 1295–1297. <https://doi.org/10.1023/A:1016222328138>

- Carrillo, E., Ruiz, A., Yeomans, H. (2004). Aislamiento, identificación y evaluación de un cultivo mixto de microorganismos con capacidad para degradar DDT. *Revista Internacional de Contaminación Ambiental*, 20(2), 69-75. www.redalyc.org/articulo.oa?id=37000203
- Clasificación recomendada por la OMS de plaguicidas por riesgo y directrices para la clasificación 2019; Organización Mundial de la Salud: Ginebra, Suiza, 2020; <https://doi.org/10.20937/rica.55003>
- Dalvie, M.; Cairncross, E.; Solomon, A.; London, L. (2003). Contamination of rural surface and ground water by endosulfan in farming areas of the Western Cape, South Africa. *Environ. Health.*: 2, 1-15. <https://doi.org/10.1186/1476-069X-2-1>
- Dhananjayan, V., Jayakumar, S., Ravichandran, B. (2019). Conventional Methods of Pesticide Application in Agricultural Field and Fate of the Pesticides in the Environment and Human Health. In K. R. R., S. Thomas, T. Volova & J. K. (Eds.), *Controlled Release of Pesticides for Sustainable Agriculture*, 1–39. 10.1007/978-3-030-23396-9_1
- Doolotkeldieva, T.; Bobusheva, S.; Konurbaeva, M. (2021). The Improving Conditions for the Aerobic Bacteria Performing the Degradation of Obsolete Pesticides in Polluted Soils Airsoil Water Res, 14. 10.1177/1178622120982590
- Holmes, R.W.; Anderson, B.; Phillips, B.; Hunt, J.W.; Crane, D.; Mekebri, A.; Connor, V. (2008). Statewide Investigation of the Role of Pyrethroid Pesticides in Sediment Toxicity in California's Urban Waterways. *Environ. Sci. Technol.*: 42, 7003–7009. <https://doi.org/10.1021/es801346g>
- Jariyal, M.; Jindal, V.; Mandal, K.; Gupta, V.K.; Singh, B. (2018). Bioremediation of organophosphorus pesticide phorate in soil by microbial consortia. *Ecotoxicol. Environ. Saf.* 159, 310–316. <https://doi.org/10.1016/j.ecoenv.2018.04.063>
- Kamika, I., & Momba, M. N. (2013). Assessing the resistance and bioremediation ability of selected bacterial and protozoan species to heavy metals in metal-rich industrial wastewater. *BMC microbiology*, 13(1), 28. <https://doi.org/10.1186/1471-2180-13-28>
- Khajezadeh, M.; Abbaszadeh-Goudarzi, K.; Pourghadamyari, H.; Kafilzadeh, F. (2020). Una cepa de *Streptomyces rimosus* recientemente aislada capaz de degradar la deltametrina como pesticida en suelo agrícola. *J. Basic Microbiol*, 60, 435–443. <https://doi.org/10.1002/jobm.201900263>
- Kosimov, D., Ergashev, R., Mavjudova, A., & Kuziev, S. (2025). Organophosphorus pesticide degradation by microorganisms: A review. *Frontiers in Bioscience-Elite*, 17(3), 38805. <https://doi.org/10.31083/FBE38805>
- Madigan, M., Martinko, J., Parker, J. (2004). *Brock. Biología de los microorganismos*. Madrid, España: Prentice Hall Iberia. <https://portalrecerca.uab.cat/en/publications/brock-biolog%C3%ADa-de-los-microorganismos/>
- Matthews, G.A. (2018). Una historia de los pesticidas; CABI: Boston, MA, EE. UU.

- Mendoza, J. C., Perea, Y. S., Salvador, J. A., Morales, J. A. y Pérez, G. (2011). Biodegradación bacteriana de plaguicidas permetrina y cipermetrina en cultivo lote. *Avances en Ciencias e Ingeniería*, 2(3), 45-55. <https://www.redalyc.org/pdf/3236/323627683005.pdf>
- Mendoza, J., Perea, Y., Salvador, J., Morales, J., & Pérez, G. (2011). Biodegradación bacteriana de plaguicidas permetrina y cipermetrina en cultivo lote. *Avances en ciencias e ingeniería*, Vol. 2(3), pp. <http://www.redalyc.org/articulo.oa?id=323627683005>
- Murugesan, A.G.; Jeyasanthi, T.; Maheswari, S. (2010); Isolation and characterization of cypermethrin utilizing bacteria from Brinjal cultivated soil. *African Journal of Microbiology Research*: 4(1), 10-13. <http://www.academicjournals.org/ajmr>
- Ortiz, M. L., Sánchez, E. (2010). Biodegradation of the organophosphate pesticide Tetrachlorvinphos by bacteria isolated from agricultural soils in México. *Revista Internacional de Contaminación Ambiental*, 26(1), 27-38. https://www.scielo.org.mx/scielo.php?pid=S0188-49992010000100003&script=sci_arttext&tlng=en
- Ortiz-Hernández, M. L., Castrejón-Godínez, M. L., Popoca-Ursino, E. C., Cervantes-Dacasac, F. R., & Fernández-López, M. (2018). Strategies for biodegradation and bioremediation of pesticides in the environment. *Strategies for bioremediation of organic and inorganic pollutants*, 95-115.
- Pérez-Lucas, G.; Vela, N.; El Aatik, A.; Navarro, S. (2020). Riesgo ambiental de contaminación de aguas subterráneas por lixiviación de pesticidas a través del perfil del suelo. En *Pesticidas: uso y abuso y su impacto en el medio ambiente*. Larramendy, M., Soloneski, S., Eds.; IntechOpen: Londres, Reino Unido; págs. 1–15.
- Racke, K. D. y Coats, J. R. (1990). *Enhanced biodegradation of pesticides in the environment*. Washington, D.C., USA: American Chemistry Society. <https://www.cabidigitallibrary.org/doi/full/10.5555/19912304292>
- Tudi, M., Daniel Ruan, H., Wang, L., Lyu, J., Sadler, R., Connell, D., ... & Phung, D. T. (2021). Agriculture development, pesticide application and its impact on the environment. *International journal of environmental research and public health*, 18(3), 1112. <https://doi.org/10.3390/ijerph18031112>
- Zhao XH, Wang J. 2012. A brief study on the degradation kinetics of seven organophosphorus pesticides in skim milk cultured with *Lactobacillus* spp. at 42 °C. *Food Chem.* 131(1):300-304. <https://doi.org/10.1016/j.foodchem.2011.08.046>

A

Alfalfa, 256, 258, 261
 anaerobic digestion, 324, 325, 326, 330, 331
 Anthracnose, 184, 189
 Aquaculture, 280, 281
Arachis hypogea, 76
 Arsenic, 307, 309, 311, 316

B

Benzoxazinoids, 58
 Biomass yield, 9, 16, 17
 Bioreactor, 310, 316
 bioremediation., 394
 Borlaug, 25, 27, 28, 29, 30

C

calcium prohexadione, 36, 38, 41, 42, 43, 44
 Centla, 289, 290, 291, 292, 293, 294
Centropomus undecimalis, 297, 298, 299, 303, 304

Ch

Chitosan, 184, 185, 191
 Chlorophyll content, 15, 16

C

consortia, 94, 95, 97, 99, 100, 101, 103, 104
Coriandrum sativum L., 184, 185, 186, 190, 191, 194
 CPUE, 289, 291, 292, 294
 cytokinins, 36, 38, 40, 41, 42, 43, 44, 46

D

Dates, 116, 122, 133, 139, 146
 Degradation, 392
 Detoxification, 310, 311

E

ENSO, 297, 298, 300

F

Fertilization, 339
 fish, 232, 233, 234, 237, 239, 240, 242
 fruit and vegetable waste, 324, 325, 331

G

Gluten, 172, 175
 Grain quality, 174
 Growth, 260

H

hybrids, 222, 223, 224, 225, 226, 227, 228
 Hydrolyzed extract, 273
 Hypopótamo, 13, 18

I

In vitro culture, 269
 irrigation, 222, 223, 225, 226, 227, 228

L

Locations, 344

M

maize, 50, 51, 53, 54, 55, 56, 57, 222, 223, 225, 227, 228
 Maize, 94, 95, 97, 98, 99
 Mango, 188
 mesquite, 232, 233, 234, 238, 240, 241, 242
 Mesquite, 256, 258, 261, 262
 Microbial, 99, 101, 104
 Morphometric analysis, 289, 293
 morphophysiological, 36, 37, 38, 45, 46

N

NDVI, 9, 10, 12, 14, 15, 18
 nile tilapia, 232
 NOM-017-PESC-1994, 289, 290, 291, 293, 294

O

Oat, 67

Oreochromis niloticus, 232, 233, 234, 241, 242, 246, 247

P

paclobutrazol, 36, 38, 40, 41, 42, 43, 44, 45, 46, 47

Pantanos de Centla, 290

Particle size, 324

physiological quality, 22, 23, 24, 29, 31

Planting, 115, 116, 119, 122, 123, 131, 133, 135, 139, 140

Prosopis juliflora, 232, 233, 234, 238, 240

Protein content, 171

R

Recreational fishing, 289

Reduced irrigation, 167, 178, 179

RGB, 65, 66, 68, 69, 70

Rheological properties, 175

S

S/I ratios, 324, 328, 329, 330, 331

saline, 222, 223

SDS sedimentation, 171, 176

size, 22, 23, 24, 25, 26, 27, 28, 29, 31

Spirulina sp, 267, 269, 270, 276

substrate-to-inoculum, 324, 325, 329, 331

T

Tabasco, 289, 290, 291, 292, 294, 297, 298, 299, 300, 301, 302, 303, 304

Tilapia, 260

tomato, 36, 37, 38, 40, 42, 43, 44, 45

Treatments, 339, 341, 343, 344, 349, 351, 352

V

Varieties, 119, 122, 123, 136, 139, 141

Vegetation indices, 65, 69

VFAs, 325, 326, 328, 331

volatile fatty acids, 325, 326

W

Water stress, 173

Weight, 116, 118, 119, 122, 123, 133, 135, 136, 139, 140, 141

wheat, 22, 23, 24, 25, 26, 27, 28, 29, 31

Wheat, 67

Wild juveniles, 283

Y

yield, 22, 24, 25, 27, 28, 29, 31

Yield, 116, 118, 119, 120, 122, 123, 125, 133, 135, 136, 137, 139, 140, 141, 143, 343, 345, 351, 352

Z

Zea mays, 75, 76, 77, 85, 222

About the editors



 **Dr. Leandris Argente-Martínez**

Professor and Senior Researcher "C" at the National Technological Institute of Mexico, Valle del Yaqui Campus (ITVY). Member of the National System of Researchers, Level 1. Professor with a Desirable Profile (PRODEP) from the Mexican Ministry of Public Education. Leader of the ITVAYA-CA-3 Academic Group. Leader of the BioSecuraNet International Network. PhD in Biotechnology Sciences. Research focuses on physiological mechanisms, anaplerotic pathways, and molecular mechanisms activated by organisms during their adaptation to abiotic stresses. Use of molecular markers of organismal tolerance to abiotic stress (salinity, drought, and heat). Application of stable isotope techniques to monitor biochemical reactions in cells and tissues. Application of univariate and multivariate experimental techniques for data processing. Contact email: oleinismora@gmail.com



 **Dra. Ofelda Peñuelas-Rubio**

Professor and Senior Researcher "C" at the National Technological Institute of Mexico, Valle del Yaqui Campus (ITVY). Member of the National System of Researchers, Level 1. Professor with Desirable Profile (PRODEP) from the Mexican Ministry of Public Education, member of the ITVAYA-CA-3 Academic Group. Mexico. She completed two postdoctoral fellowships (January 2016 - December 2017) within the CONACYT National Fellowship Program at the Interdisciplinary Research Center for Regional Integral Development, Sinaloa Unit, of the National Polytechnic Institute, in the area of Rhizosphere Molecular Ecology. She holds a PhD in Sciences specializing in Biotechnology. Contact email: ofeperub@gmail.com



 **Dr. Joe Luis Arias-Moscoso**

Professor and Senior Researcher "C" at the National Technological Institute of Mexico, Valle del Yaqui Campus (ITVY). Member of the National System of Researchers, Level 1. Professor with Desirable Profile (PRODEP) from the Mexican Ministry of Public Education, member of the ITVAYA-CA-3 Academic Group. Mexico. She completed two postdoctoral fellowships (January 2016 - December 2017) within the CONACYT National Fellowship Program at the Interdisciplinary Research Center for Regional Integral Development, Sinaloa Unit, of the National Polytechnic Institute, in the area of Rhizosphere Molecular Ecology. She holds a PhD in Sciences specializing in Biotechnology. Contact email: jarias.moscoso@itvy.edu.mx



9786585756792



BioSecuraNet

**Red Internacional de Biotecnología y
Estrategias Innovadoras
para la Seguridad Alimentaria Global**

Pantanal Editora

Rua Abaete, 83, Sala B, Centro. CEP: 78690-000

Nova Xavantina – Mato Grosso – Brasil

Telefone (66) 99682-4165 (Whatsapp)

<https://www.editorapantanal.com.br>

contato@editorapantanal.com.br