

SUSTAINABLE REUSE AND RECYCLING OF AGRO-INDUSTRIAL EFFLUENT

Edited by ABU ZAHRIM YASER,
PRAMILA TAMUNAIDU AND JUNIDAH LAMAMING



Sustainable Reuse and Recycling of Agro-Industrial Effluent

Combating climate change and securing water for future generations require rethinking waste as opportunity. This book presents a timely and accessible roadmap for transforming agro-industrial effluent from an environmental liability into a suite of value-added, sustainable resources.

At its core, the volume systematically covers the science and technology of effluent valorization: recovering inherent energy for bioenergy, extracting phosphorus for cleaner fertilizer production, and purifying water to standards suitable for irrigation or non-potable reuse. It goes further, detailing the conversion of effluent into biofertilizers, liquid nutrient formulations, and microalgae biomass, and exploring its use as a plant growth stimulant. Each pathway is framed within a circular water economy, emphasizing operational efficiency, alignment with SDG 6, 7, and 12, and the integration of environmental, societal, and economic impact assessments. Practical processing methods, resource recovery strategies, and quality upgrading techniques are presented so that reuse is both technically viable and environmentally responsible.

Original and actionable, this book offers an integrated framework that reframes effluent as a multipurpose resource rather than waste. It demonstrates advantages like phosphorus retrieval without relying on sewage sludge, and provides clear guidance for researchers, engineers, technologists, policymakers, and agro-industry stakeholders seeking to implement sustainable effluent management at scale.

Salient features to stress in promotion include:

This book's uniqueness lies in its holistic and practical reframing of agro-industrial effluent, from environmental burden to a diversified resource portfolio. It integrates cutting-edge recovery technologies including energy, nutrients, and biomass with water purification, framed explicitly against global sustainability goals (SDG 6, 7, and 12), and evaluates outcomes across environmental, societal, and economic dimensions. Promotion should stress its interdisciplinary utility (researchers, engineers, industry, policy), its real-world applicability with actionable processing pathways, and its novel comparison of resource recovery strategies within a circular economy paradigm.



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Preface

The accelerating growth of agro-industrial activities, while vital for economic development and food security, presents escalating challenges in the management of effluent and waste streams. In particular, the environmental impact of improperly treated or disposed agro-industrial effluents necessitates urgent, sustainable, and scientifically grounded interventions. This book, *Sustainable Reuse and Recycling of Agro-Industrial Effluent*, aims to serve as a comprehensive reference that addresses these challenges through interdisciplinary perspectives and practical innovations.

This book brings together research and case studies that explore the recovery and reuse of valuable resources from effluents, with a strong emphasis on environmental protection, socioeconomic development, and the transition towards a circular economy. Various chapters investigate the potential of palm oil mill effluent (POME) as a substrate for the production of biogas, the cultivation of microalgae, and the generation of struvite as a slow-release fertilizer, demonstrating a closed-loop system that benefits both industry and the environment.

Technologies such as membrane filtration, constructed wetlands, and aquaponics are explored as viable treatment and reuse strategies. These systems not only reduce the pollutant load in agro-industrial effluents but also enhance water and nutrient recovery, aligning with the principles of the blue-green economic model. In addition, the use of cellulose-based materials from agricultural waste for effluent treatment reflects an innovative and biodegradable alternative to conventional methods.

The book also addresses the complex interactions between agricultural and socioeconomic factors,

emphasizing community involvement, policy integration, and economic incentives in achieving sustainable wastewater management. The role of leachate control and nutrient recycling in both rural and industrial contexts is discussed, showcasing scalable models that can be adopted globally.

By compiling advanced research, field applications, and policy insights, this book contributes to a deeper understanding of how agro-industrial effluents can be transformed from environmental burdens into resources of value. It is our hope that this work will inspire further innovation and collaboration among researchers, practitioners, and policymakers striving for a sustainable and resilient agro-industrial future.

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18 Enhancing Soil Irrigation and Plant Growth

The Role of Inorganic Nutrients from Agro-industrial Effluents

Maya Asyikin Mohamad Arif and Dayang Norafizan Awang Chee

KEY INORGANIC NUTRIENTS FROM AGRO-INDUSTRIAL EFFLUENTS

Agro-industrial wastewater is a significant source of inorganic nutrients, particularly nitrogen (N), phosphorus (P), and potassium (K), which are essential for plant growth and development. These macronutrients are crucial for various physiological processes, such as photosynthesis, root growth, and crop yield. These nutrients are often present in significant quantities in various agro-industrial waste streams and can be recovered for use in agriculture. Nitrogen is a common nutrient found in effluents from processes such as anaerobic digestion of agro-industrial waste, municipal waste, and slaughterhouse effluents. It is often recovered and used as a fertilizer to enhance plant growth and development (Uald-Lamkaddam et al., 2021; Mehta et al., 2016; Menegassi et al., 2020), playing a crucial role in the synthesis of chlorophyll, proteins, and nucleic acids. Phosphorus is another essential nutrient present in agro-industrial effluents, crucial for plant development and is often used in fertilizers (Uald-Lamkaddam et al., 2021; Mehta et al., 2016; Negassa et al., 2012). Phosphorus is involved in energy transfer, root development, and crop maturation. It can be recovered from sources like sugarcane processing waste, municipal waste, and other agro-industrial residues. Potassium, on the other hand, is crucial for maintaining plant water status, disease resistance, and overall plant vigor (Singh et al., 2010; Srivastava et al., 2020; Hatfield & Walthall, 2015).

The application of wastewater containing these inorganic nutrients has been shown to reduce the cost of crop production by 10–20%, making it an attractive option for resource-constrained farmers (Khalid et al., 2018). The importance of inorganic nutrition for crop production is evident with the 2010 estimate for world consumption of nutrients amounting to 150 million metric tons, and projected crop production by 2030 is expected to increase by over 50% for corn, wheat, and rice, which will require a

50% increase in the use of nutrients over current levels (Hatfield & Walthall, 2015). However, the escalation in the cost of chemical fertilizers, particularly N, P, and K, coupled with related ecological concerns, has shifted the attention of the scientific and farming community toward integrated nutrient management strategies that utilize both organic and inorganic nutrient forms (Singh et al., 2010). The management of urban waste and wastewater is crucial not only for managing their quantity but also for reducing our dependency on non-renewable resources and sustaining the environment.

The application of agro-industrial wastewater to agricultural land can provide a cost-effective and sustainable means of supplementing these essential nutrients, reducing the need for synthetic fertilizers and promoting a more circular economy. However, the proper management and treatment of this wastewater are crucial to mitigate potential environmental and health risks associated with its use. The high concentrations of inorganic nutrients in agro-industrial wastewater can have both beneficial and detrimental effects on agricultural soils. While the presence of these nutrients can enhance soil fertility and crop productivity, excessive levels can lead to soil contamination, groundwater pollution, and adverse impacts on plant growth.

Several studies have highlighted the potential benefits of utilizing agro-industrial wastewater for irrigation and fertilization purposes. It has been reported that wastewater application can provide enough macronutrients to soil and plants, reducing the cost of crop production by up to 20% (Khalid et al., 2018). However, it is essential to ensure that the wastewater is adequately treated, and the composition is adjusted to meet the approved water quality standards for irrigation (Egbuikwem et al., 2021). Having identified the key inorganic nutrients present in agro-industrial effluents, the next step is to explore the methods available for their efficient recovery. Various technological approaches have been developed to extract and concentrate these valuable resources, ensuring they can be repurposed effectively.