International Journal of Research in Agronomy 2024; 7(6): 371-376

E-ISSN: 2618-0618
P-ISSN: 2618-060X

www.agronomyjournals.com
2024; 7(6): 371-376
Received: 02-03-2024
Accepted: 07-04-2024

Prachi Srivastava
MSc Scholar, Department of Agronomy, Lovely Professional University, Phagwara, Punjab, India

Navjot Rana
Assistant Professor, Department of Agronomy, Lovely Professional University, Phagwara, Punjab, India

Rajesh Kumar
Assistant Professor, Department of Agronomy, Lovely Professional University, Phagwara, Punjab, India

Shivanshu Ladohia
MSc Scholar, Department of Agronomy, Lovely Professional University, Phagwara, Punjab, India

Swati Mehta
Assistant Professor, Department of Agronomy, Lovely Professional University, Phagwara, Punjab, India

Corresponding Author:
Navjot Rana
Assistant Professor, Department of Agronomy, Lovely Professional University, Phagwara, Punjab, India

From emissions to agriculture: A comprehensive study of sulfur cycle alterations

Prachi Srivastava, Navjot Rana, Rajesh Kumar, Shivanshu Ladohia and Swati Mehta

DOI: https://doi.org/10.33545/2618060X.2024.v7.i6f.897

Abstract
This review examines how humans have altered Earth's sulfur cycle, causing environmental damage. It examines how changing this cycle affects the environment and health. The study discusses natural sulfur cycle's diverse sources, sinks, and mechanisms, starting with its importance to life and ecosystems. Industrial emissions and agricultural practices are important sulfur cycle disruptors. Next, the paper discusses intervention methods for such sulfur fertilizers, emission control, genetic engineering, and sulfur-metabolizing bacteria. Physicochemical approaches including soil amendments and novel industrial emission technologies are also investigated for sulfur dynamics. The impact of sulfur cycle modification on ecosystems and human health is key to the analysis. Environmental implications on plant and microbial communities, aquatic ecosystems, biodiversity, air and water quality, respiratory health, and human well-being are investigated. The research also discusses sulfur cycle modification issues such as technological restrictions, unanticipated impacts, and risks. To make sulfur cycle alteration safe and effective, several problems must be addressed. In the future, the assessment recommends creating sustainable technology and aligning sulfur cycle manipulation with climate change mitigation aims. The review synthesizes sulfur cycle manipulation's mechanics, impacts, and future directions to inform environmental stewardship and sustainable practices.

Keywords: Sulfur cycle, sulfur emission, anthropogenic effect, sulfur metabolizers

Introduction

The Sulphur Cycle is a riveting performer in Earth's complicated natural processes, sustaining ecosystem balance. Humans now control this basic process, affecting its tempo and rhythm as stewards of this dynamic stage [1]. Our interest in the Sulphur Cycle has increased as observers and active players trying to comprehend and manage its complicated dynamics. This review explores Sulphur Cycle Manipulation, a fascinating topic that combines science and environmental management. Next, we explore Earth's theater's backstage performers and catalysts that shape the Sulphur Cycle. From volcanic crescendos that release sulphur compounds into the atmosphere to the delicate sync of microbial transformations in soils and oceans, every step in this cycle is crucial to life on Earth [2]. Understanding and managing the Sulphur Cycle becomes more important as mankind faces new challenges like climate change.

Geoengineering options like solar radiation management involve modifying stratospheric sulphur aerosols to affect Earth's energy balance. Rearranging the placement of items in a layout requires careful consideration of global ramifications. Sulphur Cycle Manipulation is a story about our role as Earth's symphonists, not only science. Readers will consider the ethical, social, and collaborative aspects of Sulphur Cycle Manipulation in this unknown territory in this review [3].

Environmental impact of mining and mine effluents like the carbon and nitrogen cycles, the sulfur cycle maintains nature's delicate equilibrium [4]. Unfortunately, human activities have interrupted this complex process locally and globally [5]. Burning fossil fuels during global industrialization releases sulfur dioxide (SO_2) and other sulfur compounds, important environmental polluters [5]. Mining produces sulfate (SO_4), another major sulfur pollutant [5]. Critical phases in the sulfur cycle include oxidative and reductive components, which should work together in a natural environment [4]. Sulfate and elemental sulfur are electron acceptors in the metabolic pathways of many anaerobic bacteria [4]. On the oxidative side, reduced sulfur compounds donate electrons to anaerobic phototrophic bacteria. These bacteria use sunlight or provide growth energy to colorless sulfur bacteria [4].

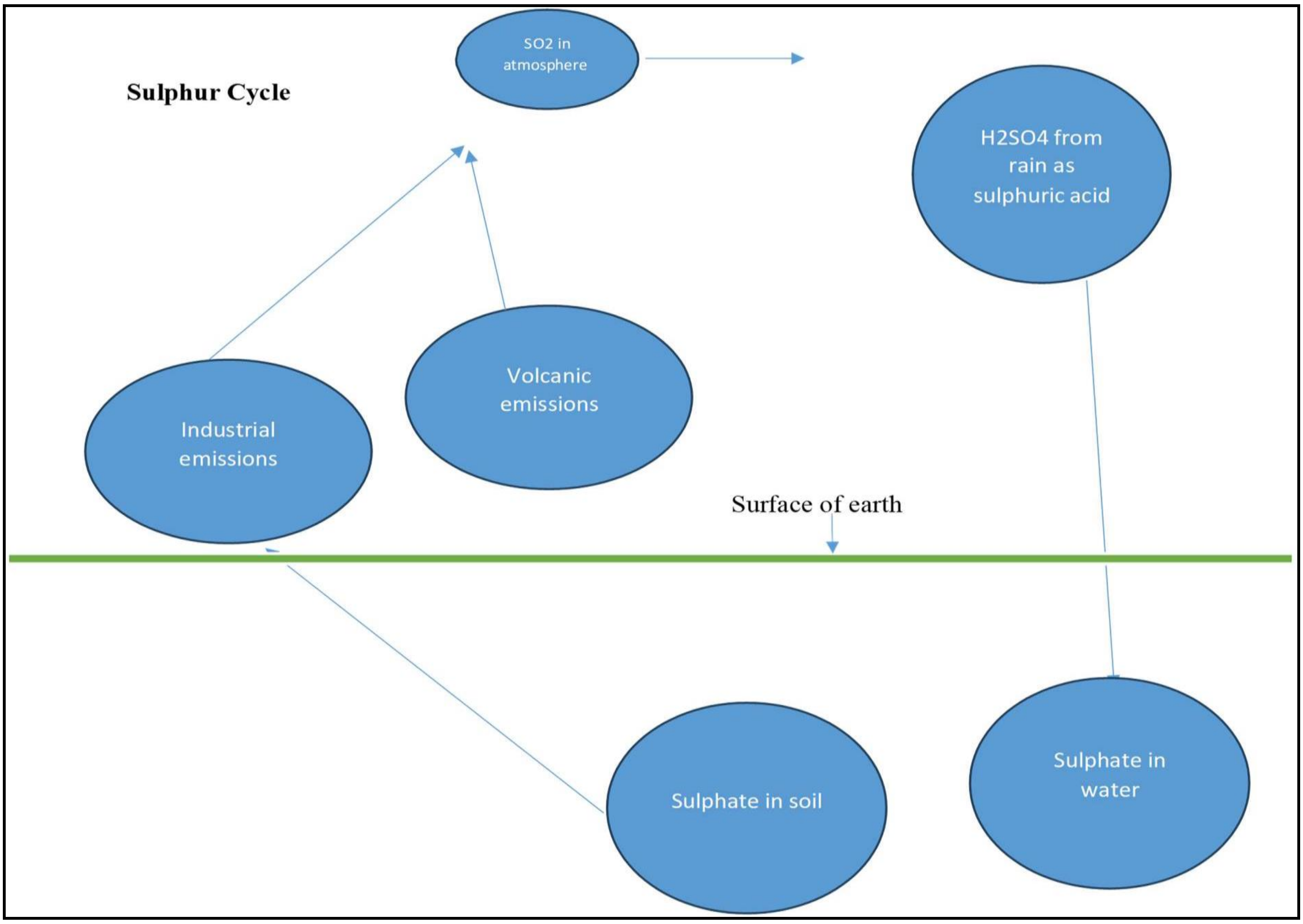

Fig 1: Sulphur cycle

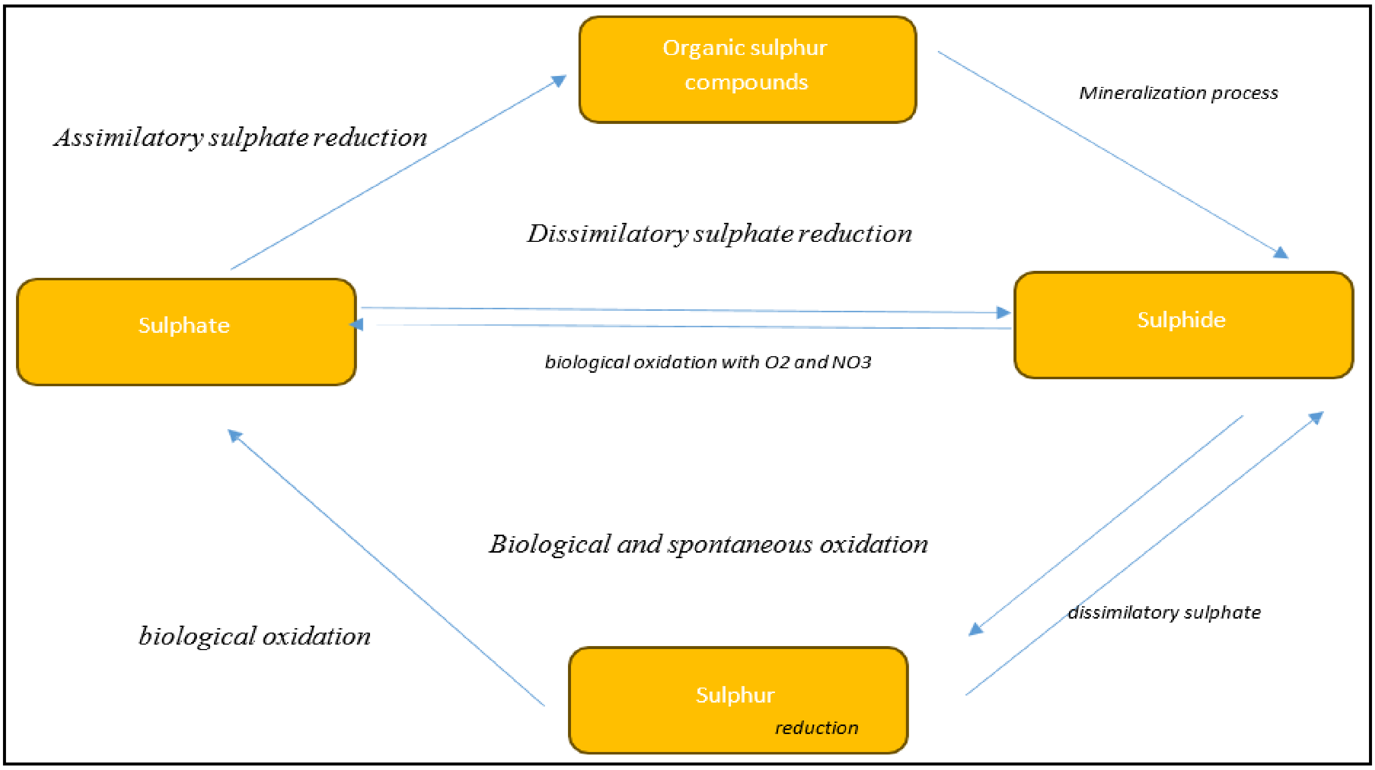

Fig 2: Biological Sulphur Cycle

In industrial management, pragmatic sulfur cycle manipulation entails producing insoluble sulfur, mostly elemental sulfur. Sustainability and easy recovery are achieved with this technique [6]. Human activity disrupts the sulfur cycle, a complex ecological system. Understanding the cycle's complexities and finding sustainable solutions that match industrial needs with environmental protection are needed to solve this problem [5]. As we explore sulfur's role in Earth's natural processes, its importance becomes clearer.

Navigating the Ripple Effect

Mining and its impact on water environments mining, a crucial business for resource extraction, often damages waterways. Not all consequences are bad. Mine waters may be suitable for public use, which could benefit the ecosystem [7]. A multifaceted examination is needed to assess environmental implications. Old mine workings release excess mine water, raising problems about its volume, geochemical characteristics, and environmental thresholds before harming groundwater and surface water [8]. This study also considers surface decant sites if aging workings overflow and spill over [9].

Dewatering, required for mining safety, illustrates the delicate balance between advancement and preservation [10]. While protecting mine workers, dewatering can be dangerous, especially if the discharged water contains pollutants. Not properly treating surface or groundwater before release can pollute the environment [11]. Underground mining affects surface water more subtly than open-pit mining. All mining can interrupt groundwater flow, influencing surface waters in hydraulic continuity with subsurface systems [7]. Mining's direct effects are frequently localized compared to dewatering and leachate seepage from waste rock heaps and tailings dams [8]. Mining and mineral processing waste accumulates in piles or tailings dams. These sites' leachate seepage pollutes surface and groundwater long after mine closure [9]. The legacy of tainted mine water haunts the South African mining industry [10]. These mine effluents contain metals and salts that deplete oxygen and threaten aquatic life. The oxidation of ferrous ions to ferric ions adds complexity, forming "yellow buoy" or "ochre" coatings. Iron hydroxides/oxyhydroxides can harm aquatic biota, causing ecological chain reactions [11]. Acidic mine water can drop to 2, therefore pH levels must be monitored. Acidity below 6.5 can impair fish and aquatic invertebrate reproduction and growth, complicating the relationship between mining and aquatic ecosystems [7]. Surface water contamination from waste rock heaps and tailings dams is common [8]. Even revegetated waste rock piles leak acidic leachates, causing decades of problems. Unlined ancient tailings dam bases can also damage surface and groundwater with leachate [9]. Navigating the complicated interaction of mining and water shows that every mining action affects aquatic ecosystems. Balance between resource extraction and environmental stewardship is ethically required.

Exploring Hydrogen's Prominent Role: A Sustainable Energy Frontier

Hydrogen gas, a clean, sustainable fuel, is a promising step toward alternative energy. In 1874, science fiction author Jules Verne predicted its relevance in "The Mysterious Island," calling hydrogen gas (H_2) the future "fuel" [12]. Chemically and biologically, hydrogen can be used as energy. Verne's insight led to the idea of hydrogen generation from a "plentiful" source like water, which continues to influence sustainable energy talks [12]. Chemical electrolysis separates water into hydrogen and oxygen. Electrolysis requires additional energy sources like coal burning to generate electricity [13]. Fermented waste products are used to make biologically produced hydrogen, which is more sustainable. Sulfate-Reducing Bacteria (SRB) use hydrogen and CO_2 to reduce sulfate, the electron acceptor [14]. Du Preez *et al*. (1992) and Van Houten (1996) used hydrogen to remove biological sulfate. SRB has advantages over MB when hydrogen is the dominant energy source [15]. Schutte & Maree (1989) pioneered hydrogen-based autotrophic sulfate reduction, showing 91% efficiency at 2.4 days hydraulic retention time (HRT). The study showed that CO_2 is essential for SRB because stopping CO_2 flow stopped sulfate reduction. SRB relies on syntrophic bacteria, which use CO_2 to generate lactate and ethanol, which SRB uses as carbon sources [16]. According to Van Houten (1996), hydrogen-utilizing SRB (HSRB) are not autotrophic and require other anaerobes to produce acetate, a vital carbon source. Hom acetogens, obligate anaerobes that use CO_2, produce acetate as their sole product of anaerobic respiration. Under hydrogen-limiting conditions, HSRB has insufficient acetate, therefore HMB may dominate. Similarly, CO_2-limiting circumstances may impair SRB respiration, revealing their metabolic routes [17]. Schutte & Maree (1989) confirmed the close relationship between hydrogen availability and sulfate reduction. Sulfate reduction stopped when hydrogen supply stopped, underscoring hydrogen's importance as an energy source and growth catalyst. Acetate synthesis flourishes in conditions containing hydrogen as an energy source and CO_2 as an electron acceptor, providing HSRB with a carbon supply for sulfate reduction, as in mine wastewater treatment [16]. Hydrogen's adaptability and symbiosis with SRB make it a likely sustainable energy source. Understanding these complicated microbial interactions is crucial to harnessing hydrogen's potential as we explore alternate energies.

Active biological sulphate reduction unleashes nature's remediation: This review explores active biological sulfate reduction technique for effluent treatment, a powerful and fast method. This active technology's strength allows it to treat huge volumes of sulphate-rich effluents quickly. Treatment relies on Sulphate-Reducing Bacteria (SRB) and organic matter working together. The adaptability of SRB makes active biological sulphate reduction beautiful. In addition to methanogenic substrates like hydrogen, format, acetate, methanol, and pyruvate [19], SRB can adapt too many intermediate products from anaerobic mineralization. Sulphate, sulphite, and thiosulphate allow SRB to interact with multiple carbon sources. Besides hydrogen and acetate, propionate, butyrate, higher and branched fatty acids, lactate, ethanol, higher alcohols, fumarate, succinate, malate, and aromatic compounds are included [18].

SRB have two oxidation patterns during VFA sulfidogenic breakdown. Some are masters in oxidizing VFA completely into carbon dioxide and sulphide. Others oxidize VFA more slowly, producing acetate and sulphide. As seen in Table [19], SRB's diverse carbon sources illuminate nature's complicated metabolic process. We learn that active biological sulfate reduction uses microbial communities to efficiently and dynamically change sulphate-rich effluents. It follows sustainable methods and opens up new effluent stream treatment options.

Table 1: Organic substrates, most commonly used for biological sulphate removal

Acetate	Ethanol	Glycerol	Pyruvate
Alanine	Format	Lactate	Succinate
Butyrate	Fructose	Malate	Sucrose
Citrate	Glucose	Propionate	Tartrate

Exploring Nature's Biochemical Cycle: Sulphur Symphony

The organic sulphur cycle gently goes across terrestrial and aquatic environments, orchestrating a beautiful interplay between prokaryotes, eukaryotes, and chemical processes. This massive show produces millions of megatons of sulfonated compounds annually, an enormous store of sulphur connected to prokaryotes' energy and carbon needs [19]. Understanding prokaryotes' processes and ecological intricacies in the organic sulphur cycle is crucial in this biochemical process. Sulfonated compound breakdown affects human health, bacterial virulence in infections, global warming dynamics, bioremediation processes including wastewater treatment, and sulphur biogeochemical cycling across varied environments [20].

From humble C1 carbon skeletons to grandiose sulphonated lipids, amino acids (like cysteine), and complex cofactors like lipoate, sulphonated substances are diverse. New sulphonated compounds are discovered, but their metabolic activities, production, and degradation processes are generally unknown [21]. Only the most common ones-sulphoquinovose, dimethylsulphoniopropionate (DMSP), taurine, isethionate, cysteine, and methionine-have been biochemically examined for their complex routes. At 600 million tons per year, macroalgae and phytoplankton create DMSP, the leading antistress chemical in aquatic environments. Bacterial decomposition in oceans, salt marshes, and coastal areas releases 300 million tons of dimethylsulphide (DMS) annually [22]. Beyond being volatile, DMS is crucial to atmospheric chemistry and global warming. It gently affects climatic dynamics by generating cloud condensation nuclei that reflect solar light [23].

DMS facilitates the global sulphur cycle by integrating terrestrial, atmospheric, and aquatic habitats. DMS carbon and sulphur operate as electron acceptors and donors or assimilate through dimethlysulphone and methanesulphinate [24]. This mesmerizing reaction shows the global sulfur cycle as a scientific marvel and a choreography that shapes our interconnected world. This reaction's steps leave lasting impressions, mimicking nature's symphony.

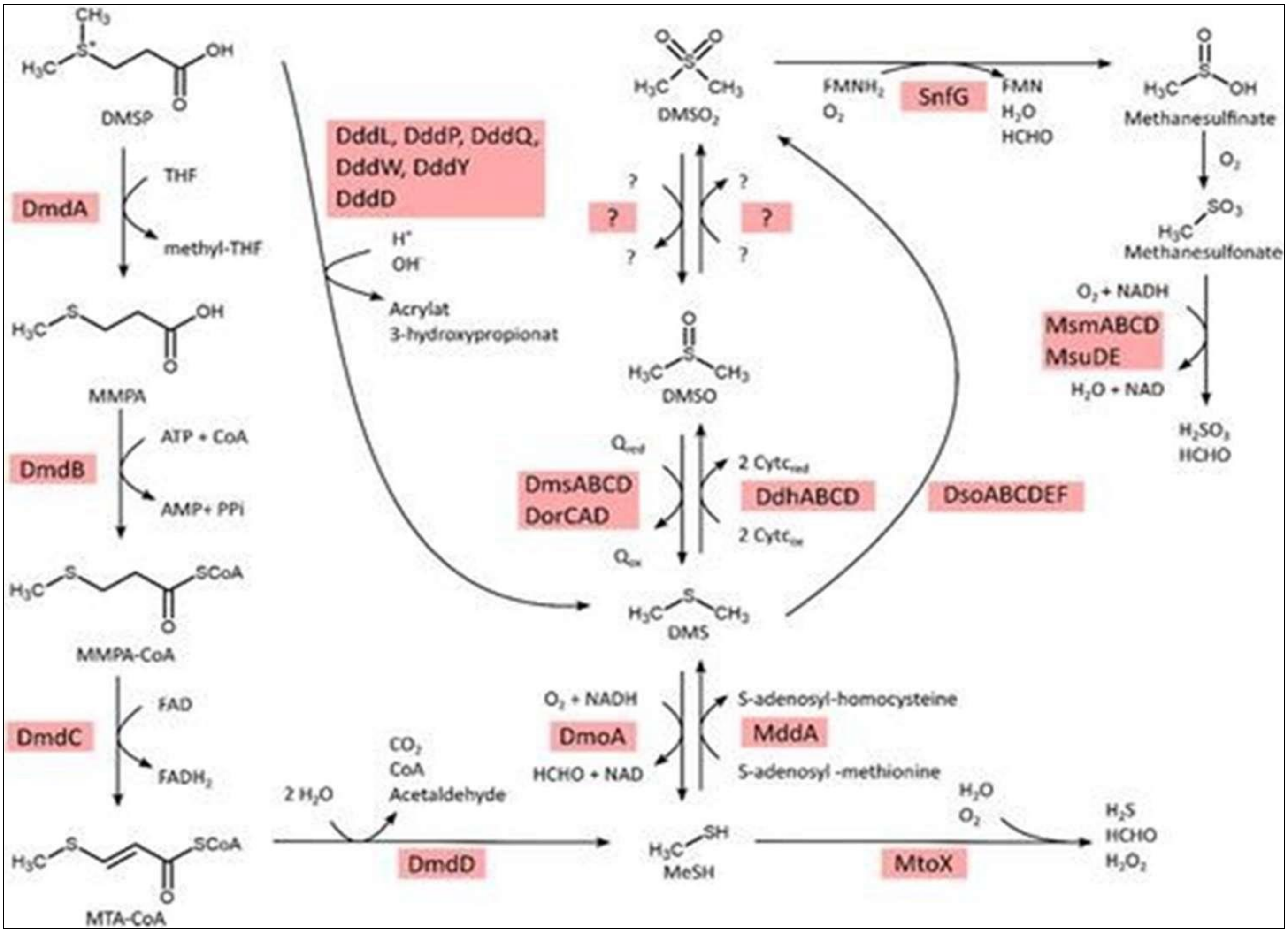

Fig 3: Prokaryotic metabolism of C1 organosulphur compounds. All proteins shown have a corresponding HMM in HMSS2. Cytc, Cytochrome c; DMSP, dimethylsulphoniopropionate; DHPS, 2,3-dihydroxypropane-1-sulphonate; DMS, dimethylsulphide; DMSO, dimethylsulphone, DM

Future Directions and Research Gaps in Sulphur Cycle Manipulation: Exploration Roadmap Many study and discovery opportunities emerge as we negotiate Sulphur Cycle Manipulation's difficult landscape. We must understand these prospective directions and identify research gaps to advance our understanding and address crucial field concerns.

1. Deciphering Microbial Interactions

Research Direction: Study the complex microbial interactions in the sulphur cycle, particularly the dynamics and linkages between microbial populations participating in sulphur transformations.

Research Gap: Current knowledge covers microbial involvement broadly. A lack of knowledge about specific microbial species, their functions, and environmental responses exists.

2. Omics Technology Integration

Research Direction: Integrate metagenomics, meta transcriptomics, and metabolomics to understand the genetic and functional possibilities of sulphur cycling microbial communities.

Research Gap: Few sulfur cycle manipulation studies have fully used sophisticated omics techniques. Bridge this gap to gain complete microbial activity insights.

3. Bioremediation Sustainability

Research Direction: Optimize sustainable bioremediation for sulphur-contaminated settings. Examine designed microbial communities for efficient sulphur removal and recovery.

Research Gap: Current strategies may not fully comprehend their long-term environmental implications and efficiency. Develop ecologically friendly and economically feasible methods in future research.

4. Effects on Ecosystem Services

Research Direction: Examine how sulphur cycle modification affects ecosystem services like soil fertility, water quality, and biodiversity.

Research Gap: Only a few studies have examined how sulfur cycle changes affect ecosystem services. Sustainable environmental management requires a holistic approach.

5. Climate resilience

Research direction: Study how sulfur cycle modification improves climate change resilience. Examine how sulphur dynamics affect greenhouse gas emissions and the carbon cycle.

Research Gap: The sulphur and carbon cycles' interconnectivity and climate change resilience need further study.

6. Tech Innovations

Research direction: Researchers should investigate electrochemical and biotechnological methods for sulphur recovery and recycling from waste streams.

Research Gap: Cutting-edge sulfur cycle manipulation technologies have received little attention. Novel approaches could transform sulfur management.

7. Cross-disciplinary cooperation

Research Direction: Researchers should work together with microbiologists, environmental engineers, chemists, and ecologists to better understand sulphur cycle dynamics.

Research Gap: Siloed research may inhibit cross-disciplinary knowledge integration. Collaborative networks could close this gap and provide greater insights.

Navigating these future research pathways and overcoming Sulphur Cycle Manipulation gaps will enable new solutions, sustainable environmental management, and a better knowledge of our ecosystems' complex processes.

Conclusion

Sulphur cycle manipulation studies show an intricate world of microbial conductors, environmental dynamism and technological progression. The sulphur cycle affects land and water terrains thereby influencing human health, weather as well as ecology. Active biological sulfate reduction and manipulation of sulfur dynamics are discussed in this paper. Understanding prokaryotic mechanisms is important for understanding the organic sulphur cycle's biochemical process. The progression of sulphonated compounds from simple carbon skeletons to complex structures makes the sulphur cycle more complicated. The future scenarios or pathways for studying sulfur cycles offer many options including improved omics technologies, sustainable bioremediation techniques, microbial interactions, and ecosystem service implications among others. In order to resolve remaining enigmas and create a sustainable future with harmonized sulphur cycles that can interlink with our planet's symphony we need collaboration, genius and interdisciplinary expertise.

References

1. Campbell BJ, Engel AS, Porter ML, Takai K. The versatile ε-proteobacteria: Key players in sulphidic habitats. Nat Rev Microbiol. 2006;4:458-468.
2. Del Valle DA, Kieber DJ, Kiene RP. Depth-dependent fate of biologically-consumed dimethylsulfide in the Sargasso Sea. Mar Chem. 2007;103:197-208.
3. Dhillon A, Teske A, Dillon J, Stahl DA, Sogin ML. Molecular characterization of sulfate-reducing bacteria in the Guaymas Basin. Appl Environ Microbiol. 2003;69:2765-2772.
4. Kuenen JG, Robertson LA. The use of natural bacterial populations for the treatment of sulphur-containing wastewater. Biodegradation. 1992;3:239-254.
5. Banks D, Younger PL, Dumpleton S. The historical use of mine drainage and pyrite oxidation waters in central and eastern England, United Kingdom. Hydrogeol J. 1996;4(4):55-68.
6. Booth CJ. The effects on longwall mining on overlying aquifers. In: Younger PL, Robbins NS, editors. Mine Water Hydrology and Geochemistry. London: Geological Society; c2000. p. 17-45.
7. Widdel F, Pfennig N. A new anaerobic, sporing, acetate-oxidizing, sulphate-reducing bacterium, Desulfotomaculum (emend) acetooxidans. Arch Microbiol. 1977;112:119-122.
8. Younger PL, Wolkersdorfer C. Mining impact on the fresh water environment: technical and managerial guidelines for catchment scale management. Mine Water Environ. 2004;23.
9. Johnson DB. Biological removal of sulphurous compounds from inorganic wastewater. In: Lens P, Hulshoff Pol L, editors. Environmental Technologies to Treat Sulphur Pollution, Principles and Engineering. London: IWA Publishing; c2000. p. 175-205.
10. Iza J. Fluidized bed reactors for anaerobic wastewater treatment. Water Sci Technol. 1991;24:109-132.
11. Ikuta K, Kitamura S. Effect of low pH exposure of adult salmonids on gametogenesis and embryo development. Water Air Soil Pollut. 1995;85:327-332.
12. Verne J. The Mysterious Island. In: Miller TG, editor. Living in the Environment. 9th ed. Belmont, CA: Wadsworth Publishing Company; c1996.
13. Stams AJM, Kremer DR, Nicolay K, Weenk GH, Hansen TA. Pathway of propionate formation in Desulfobulbus propionicus. Arch Microbiol. 1984;139:167-173.
14. Du Preez LA, Odendaal JP, Maree JP, Ponsonby G. Biological removal of sulphate from industrial effluents using producer gas as energy source. Environ Technol. 1992;13:875-882.

15. Fan LT, Lee YH, Beardmore DH. Mechanism of the enzymatic hydrolysis of cellulose: effects of major structural features of cellulose on enzymatic hydrolysis. Biotechnol Bioeng. 1980;22:177.
16. Schutte CE, Maree JP. Autotrophic sulphate reduction using hydrogen as the energy source. In: Proceedings of the 2nd Anaerobic Digestion Symposium. Bloemfontein: University of the Orange Free State; c1989.
17. Van Houten RT. Biological sulphate reduction with synthesis gas. PhD Thesis. Wageningen: Agricultural University; c1996.
18. Bock A, Prieger-Kraft A, Schonheit P. Pyruvate - a novel substrate for growth and methane formation in Methanosarcina barkeri. Arch Microbiol. 1997;161:334-336.
19. Moran MA, Durham BP. Sulfur metabolites in the pelagic ocean. Nat Rev Microbiol. 2019;17(11):665-678.
20. Dhouib R, Nasreen M, Othman DSM, Ellis D, Lee S, Essilfie AT, *et al*. The DmsABC Sulfoxide Reductase Supports Virulence in Non-typeable Haemophilus influenzae. Front Microbiol. 2021;12:686833.
21. Dhouib R, Nasreen M, Othman DSM, Ellis D, Lee S, Essilfie AT, *et al*. The DmsABC Sulfoxide Reductase Supports Virulence in Non-typeable Haemophilus influenzae. Front Microbiol. 2021;12:686833.
22. Kiene RP, Linn LJ, Bruton JA. New and importan; c2000.
23. Schäfer H, Myronova N, Boden R. Microbial degradation of dimethylsulphide and related C1-sulphur compounds: organisms and pathways controlling fluxes of sulphur in the biosphere. J Exp Bot. 2010;61(2):315-334.
24. Lovelock JE, Maggs RJ, Rasmussen RA. Atmospheric dimethyl sulphide and the natural sulphur cycle. Nature. 1972;237:452-453.