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# GREEN CHEMISTRY: A PROPITIOUS ROUTE FOR SUSTAINABLE AGRICULTURE

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**Abstract -** Green chemistry is a science-driven approach focused on designing chemical products and processes that reduce or eliminate the use and generation of hazardous substances. Its principles promote waste minimization, safer chemical synthesis, energy efficiency, and the use of renewable materials, contributing to sustainable development across industries. This concept has significant relevance in agriculture, where it supports the development of eco-friendly fertilizers, biodegradable pesticides, and organic soil amendments. These innovations improve nutrient use efficiency, reduce environmental pollution, and enhance soil health. Studies have shown that controlled-release fertilizers made from biopolymers, and amendments like compost, vermicomposting, and bio char, can effectively suppress soil borne pathogens and improve crop productivity without compromising ecosystem integrity. Green chemistry plays a critical role in meeting global challenges such as food security, climate change, and sustainable agriculture. By shifting focus from remediation to prevention, it provides a pathway toward cleaner technologies, healthier ecosystems, and a more resilient agricultural system.

**Keywords:** Green Chemistry, Sustainable Agriculture, Environment Protection, Alternative Energy, Healthier Ecosystem.

## 1. INTRODUCTION

Green chemistry is the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances. Green chemistry applies across the life cycle of a chemical product, including its design, manufacture, use, and ultimate disposal. Green chemistry is a science-based philosophy of designing chemicals and processes with the intention of making them less hazardous and more sustainable. It applies to the life cycle of a chemical, from creation to disposal. Using green chemistry is part of sustainable design — a way for scientists and engineers to provide innovative and creative ways to reduce waste, conserve energy, and replace hazardous chemicals with safer alternatives. Green chemistry has been used in a wide variety of products and processes, from the medical field to computer technology to household paint and more (19). Loste et al 2019 mentioned some important advantages of green chemistry as under:

Prevents pollution at the molecular level
Is a philosophy that applies to all areas of chemistry, not a single discipline of chemistry
Applies innovative scientific solutions to real-world environmental problems
Results in reduction of source
Reduces the negative impacts of chemical products and processes on human health and the environment
Lessens and sometimes eliminates hazards from existing products and processes
Designs chemical products and processes to reduce their intrinsic hazards

Green chemistry reduces pollution at its source by minimizing or eliminating the hazards of chemical feedstocks, reagents, solvents, and products. This is not the same as cleaning up pollution (also called remediation), which involves treating waste streams (end-of-the-pipe treatment) or cleanup of environmental spills and other releases. Remediation may include separating hazardous chemicals from other materials, then treating them so they are no longer hazardous or concentrating them for safe disposal. Most remediation activities do not involve green chemistry. Remediation removes hazardous materials from the environment; on the other hand, green chemistry keeps the hazardous materials from being generated in the first place. If a technology reduces or eliminates the hazardous chemicals used to clean up environmental contaminants, this technology would also qualify as a green chemistry technology. One example is replacing a hazardous sorbent [chemical] used to capture mercury from the air for safe disposal with an effective, but non-hazardous sorbent. Using the non-hazardous sorbent means that the hazardous sorbent is never manufactured and so the remediation technology meets the definition of green chemistry.


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### 1.1 Principles of Green Chemistry

To understand the concept more in depth, following are the few principles of green chemistry (Abdussalam-Mohammed et al 2020)-

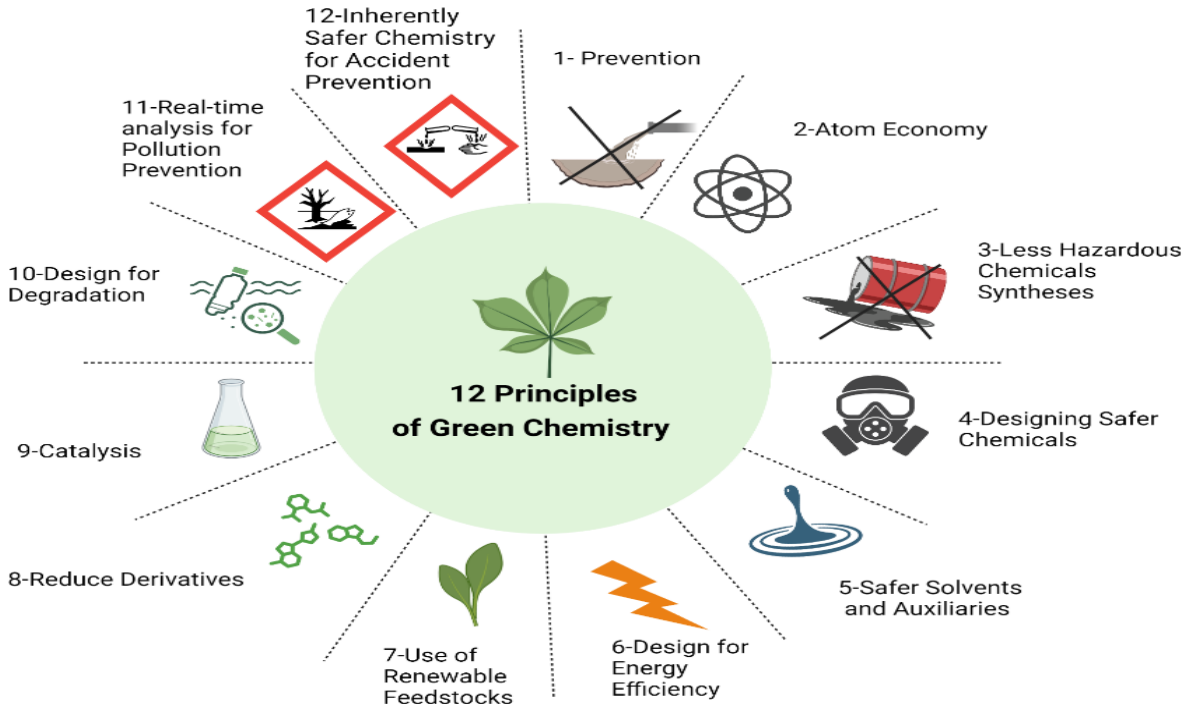


**Fig. 1.1 Principles of Green Chemistry (Dorra Saidi)**

**Prevention-** It is better to prevent waste than to treat or clean up waste after it is formed.
**Atom economy-** Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
**Less hazardous chemical syntheses-** Wherever practicable, synthetic methodologies should be designed to use and generate substances that possess little or no toxicity to human health and the environment.
**Designing safer chemicals-** Chemical products should be designed to preserve efficacy of function while reducing toxicity.
**Safer Solvents and Auxiliaries-** The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.
**Design for energy efficiency-** The use of auxiliary substances (e.g. solvents, separation agents, etc.) should be made unnecessary Wherever possible and, innocuous when used.
**Use of renewable feedstock-** Energy requirements should be recognized for their environmental and economic impacts and should be minimized. Synthetic methods should be conducted at ambient temperature and pressure.
**Reduce derivatives-** A raw material or feedstock should be renewable rather than depleting wherever technically and economically practicable.
**Catalysis Reduce derivatives -** Unnecessary derivatization (blocking group, protection/ deprotection, temporary modification) should be avoided whenever possible. Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
**Design for degradation-** Chemical products should be designed so that at the end of their function they do not persist in the environment and break down into innocuous degradation products.
**Real time analysis for pollution prevention-** Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances and
**Inherently safer chemistry for accident prevention-** Substances and the form of a substance used in a chemical process should be chosen to minimize potential for chemical accidents, including releases, explosions, and fires.
Green chemistry and agriculture are closely related through their shared goal of sustainability, environmental protection, and reducing harmful impacts on ecosystems and human health. In 2001, at University of Colorado, Boulder, IUPAC CHEMRAWN XlV Conference on Green Chemistry: Towards Environmentally Benign Processes and Products, was organized and in this conference a number of chemists discuss the effect of agricultural and industrial activities on atmospheric chemistry. They advised “design-for-environment “framework to work with consumers and assure the safety of foods and crops develop by green methods for green agriculture practices as mentioned by S. Bandari et al 2018. Green chemistry principles are applied to


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develop safer, more sustainable chemicals used in agriculture, such as:
**Fertilizers:** Development of controlled-release or bio-based fertilizers that minimize runoff and nutrient pollution.
**Pesticides and Herbicides:** Designing biodegradable, selective, and non-toxic agrochemicals that break down into harmless byproducts.
**Soil Amendments:** Use of natural or low-toxicity materials to improve soil health and structure without harmful residues.

## 2. USE OF GREEN CHEMISTRY IN FERTILIZERS

Using green chemistry in fertilizer development is important because it addresses key environmental, health, and efficiency challenges associated with traditional fertilizers. Green chemistry in fertilizers is essential for promoting sustainable and environmentally friendly agriculture. It helps reduce pollution by minimizing nutrient runoff and groundwater contamination, thereby protecting water bodies from eutrophication. These fertilizers are designed for higher efficiency, releasing nutrients in a controlled way to ensure better uptake by crops and reduce waste. Green chemistry also lowers the carbon footprint by using renewable materials and energy-efficient production methods. Additionally, it protects soil health by preserving beneficial microorganisms and enhancing long-term fertility. With safer, non-toxic, and biodegradable formulations, green fertilizers are better for farmers, ecosystems, and consumers. Overall, they support the shift toward more sustainable and climate-resilient agricultural practices. Eddarai et al 2024 in their study mentioned that biopolymer-based controlled released fertilizers use eco-friendly materials; chitosan, starch, and cellulose, supporting a circular economy and reducing environmental harm therefore controlled released fertilizers improve efficiency but face limitations due to high costs and environmental impacts. Another author Guo et al 2022 worked on an important scientific basis for China's provinces (cities) to formulate carbon emission reduction policies and concluded that the Green finance will make a huge contribution to reducing fertilizer use and agricultural carbon emissions within a decade. Withers et al 2015 adressed that green chemistry and green engineering can be applied to help close the global P cycle by addressing three sustainability challenges: (1) consume less PR and with greater efficiency, (2) minimise P losses and generation of waste P that can no longer be re-used, and (3) set economically, socially and environmentally acceptable P sustainability targets to lower P demand. Similarly Mathur et al 2016, Esa et al 2022 and Abdelsattar et al 2023 concluded that latest generation Green Technology FQI products take care of these fertilizer quality issues efficiently and economically. Proper application of such Fertilizer Quality Improvement products not only improve the quality of fertilizer and saves money, but also add value to the fertilizer product.

### 2.1 Green chemistry in Soil Amendments

Soil degradation is the major obstacle for sustainability of crop production and human survival. With deteriorating climate change effects, of erratic rainfall patterns, sudden increase in rainfall intensity and temperature fluctuation around the world is a serious challenge for farmers, environmentalists, and common man. Increasing pressure of human population, that has been estimated to rise up by 9.5 billion by 2050 would increase drastically food demand [Glaesner et al 2014]. Sustainable crop production and improving soil quality is a major concern which need development of management strategies without negative effect on environment can lead to food security and natural resource conservation. In this approach, soil organic matter plays indispensable role which is directly related with soil ecosystem services and functions for long term oilseed productivity. Also due to the large output and potential ecological risks, disposal of engineering abandoned soils (EAS) has become an enormous challenge for human society (Yang et al 2021). Soil management for sustainable agriculture can be achieved by improving soil organic matter/ organic carbon of soil through organic amendments addition to soil at regular time intervals. Following the practices of green chemistry one gets many advantages as shown in the figure 2 (Aslam et al 2022). Thus, soil organic matter will help to conserve or restore soil fertility to meet present and future food requirement, with acceptable impact on environment Diacono et al 2010 and Chun et al 2018. Soil health is directly related to soil and crop productivity and is being recognized as a major component for mitigating climate change effect and food security.
Soil health is closely associated with soil quality, in which the biological health of the organism in soil is critical for soil resiliency and ecosystem services [Costantini et al 2022]. In this direction Angelova et al 2013 worked on the effect of organic amendments on soil chemical characteristics and observed that the application of compost and vermicompost reduced the amount of aggressive fulvic acids, organic matter components that pose a potential environmental risk. The results of the study indicated that soil application of compost and vermicompost decreased DTPA-extractable levels of heavy metals in the soil. Also, Othman et al 2018 concluded that plant-based fertiliser can be an ideal option for improving soil and head quality of artichokes, but animal-based fertilisers may be an appropriate choice for organic farmers when yield and cost are the main concerns.


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**Fig. 2.1 Green chemistry and sustainable agriculture (Aslam et al 2022)**

Further amendment like biochar was studied by Bamdad et al 2022 and they concluded that biochar is a promising microbial carrier together with its influence on the soil biota including microorganisms and plants. Application of pesticides is extensively used for the current control of pathogens which provide only partial protection and highly pollute the environment. The use of organic amendments is the best preventive practice for the suppression of soilborne pathogens. These amendments changed the soil's physical, chemical, and microbial characteristics. Biochar, manure, and compost are the main organic amendments that are used to suppress plant diseases because of their high nutritional value. In nutshell, the use of soil organic amendments is a safe future for the soil and plant's health as well.

## CONCLUSION

Green chemistry represents a transformative approach to chemical design and application, grounded in sustainability, efficiency, and safety. By minimizing or eliminating the use and generation of hazardous substances throughout the life cycle of chemical products—from synthesis to disposal—it offers proactive solutions to environmental and health challenges. Unlike remediation, which treats pollution after it has occurred, green chemistry seeks to prevent it at the source, making it a more sustainable and long-term strategy. The principles of green chemistry have far-reaching applications across industries, including agriculture, where they are used to develop eco-friendly fertilizers, biodegradable pesticides, and effective soil amendments that enhance soil health without degrading ecosystems.

In agriculture, the integration of green chemistry contributes to climate-resilient practices by improving fertilizer quality, reducing nutrient loss, conserving soil organic matter, and mitigating the risks associated with chemical pollution. Research has shown that biopolymer-based fertilizers, organic amendments, and biochar can enhance nutrient use efficiency while reducing environmental harm. Furthermore, green chemistry supports global sustainability goals by addressing key issues such as phosphorus cycling, carbon emissions, and food security.

Overall, green chemistry is not merely a scientific discipline but a strategic framework for designing a healthier, safer, and more sustainable future. Its application in industry and agriculture is essential for achieving environmental stewardship, economic viability, and long-term societal well-being.

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