Integrating Green Chemistry into Sustainable Agricultural Practices: Addressing Global Environmental Challenges

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Abstract. The agricultural advancements of the 20th century, particularly the introduction of chemical fertilizers and pesticides, led to a significant boost in crop yields and food production. However, many of these substances persist in the environment, contributing to soil, water, and air pollution while also entering the food chain and posing risks to human health. As humans face escalating environmental challenges in the 21st century, including climate change, resource depletion, and biodiversity loss, the need for sustainable agricultural practices has become more critical than ever. Green chemistry, with its 12 fundamental principles, offers a pathway to reduce the ecological impact of agriculture while maintaining or even improving productivity. This paper explores the definition of green chemistry, its relationship with sustainable agriculture, and the impact of ten major global environmental issues on farming. It also provides practical solutions for integrating green chemistry into agriculture to minimize negative environmental impacts and promote a more sustainable future for food production.

Keywords: Green chemistry; agriculture; environmental challenge.

1. Introduction

Green chemistry is a subject that can be understood from different perspectives. Wenping Liang and Jin Tang discussed it from three aspects: science, environment and economy [1]. Firstly, for science, green chemistry breaks the traditional chemistry rules and tries to find a new way to update and develop it. Secondly, for the environment, instead of using anything colorable, it tries to solve the pollution from their origin. Finally, for the economy, it makes use of resources and energy wisely and lowers the cost. It hammers at changing the route of chemical industry production, which only solves the problem when the problem occurs into eliminates the pollution from its origin.

Green chemistry tries not to use any poisonous or harmful sources, catalysts, solvents or any product-by-product. Improving the atomic economy and reducing the release of useless goods. Therefore, it can be a good way to achieve sustainable development. With the help of green chemistry, agriculture can reduce the waste of resources due to the increasing atom economy. Combined with the definition of green chemistry, the points that green agriculture needs to pay attention to can be summarized into three parts: i) maintaining the ability to increase production so that it can provide enough food for the increasing population, the method that would lower the production is inadvisable; ii) decrease negative externality and increase positive externality; iii) reduce pollution and use resources efficiently. According to Qiucheng Tan, green agriculture includes good agricultural practice, organic agriculture, ecological agriculture, and conservation agriculture [2].

2. The Main Twelve Directions in Green Chemistry

As the development of green chemistry, the primary focus of green chemistry, also referred to as the "12 principles," according to Qingshi Zhu, revolves around addressing the following concerns: (1) prioritizing the prevention of pollution at its source rather than relying on end-of-pipe treatments; (2) promoting synthetic methods with high atom economy, ensuring maximum incorporation of atoms involved in the process into the final product; (3) minimizing or eliminating the use and generation of toxic substances that pose risks to human health and the environment during synthetic processes; (4) designing chemical products that exhibit both high efficiency and low environmental toxicity

levels; (5) reducing reliance on auxiliary materials like solvents and, when necessary, ensuring their harmlessness; (6) conducting production processes under mild temperature and pressure conditions with minimal energy consumption requirements; (7) utilizing renewable raw materials whenever feasible, particularly for replacing mineral resources such as petroleum and coal with biomass alternatives; (8) minimizing by-product formation during chemical reactions; (9) employing highly selective catalysts for enhanced efficiency; (10) facilitating degradation of chemical products into harmless substances after use, allowing them to enter natural ecological cycles seamlessly; (11) developing timely analytical techniques for monitoring hazardous substance formation throughout processes; (12) selecting materials participating in chemical reactions cautiously to minimize accident risks [3].

3. Top Ten Contemporary Global Environmental Issues

This section discusses the top 10 contemporary global environmental issues and their effect on them in agriculture.

3.1. Top Ten Issues

According to Qingshi Zhu, the primary environmental issues facing the world today include: (1) air quality deterioration; (2) thinning of the ozone layer; (3) climate change driven by global warming; (4) degradation of marine ecosystems; (5) water shortages along with pollution; (6) land degradation and desertification trends; (7) significant loss of forest areas; (8) decline in biodiversity; (9) widespread environmental contamination; (10) hazardous substances and toxic waste [3].

3.2. Some Effects Caused by Those Issues

3.2.1 Air quality deterioration

For air pollution, SO_2 is one of the main gases which does harm farming. According to Wanru Dun and Zhonghua Qiu, In recent times, extensive research has been conducted nationwide to investigate the impact of SO_2 and HF on crops in terms of their mechanism, dosage, and domain value. The findings indicate that various types of crops experienced a reduction in plant height as well as stem and leaf weight following exposure to SO_2. Furthermore, their growth potential was compromised, resulting in delayed flowering and fruiting, along with a decrease in yield [4]. Table 1 below shows the effects of SO_2 on rice at different growth stages, according to Wanru Dun and Zhonghua Qiu. SO_2 in the atmosphere is very harmful to the crops.

Table 1. Effects of SO_2 on rice at different growth stages

Date	Growth stage	Average yield per plot		Average number per panicle	TKW (g)
		gram	%		
Control group	/	864	100	43.6	27.6
March 19	jointing stage	762	88.2	43.7	24.3
April 15	booting stage	573	66.3	44.2	22.3
April 26	flowering stage	392	45.4	17.6	25.8
May 23	milk stage	730	84.5	43.2	24.1

3.2.2 Thinning of the ozone layer

According to Jicheng Li, Ozone easily enters plant leaves through gas exchange in stomata. In plants, powerful oxidation actually burns the cell membrane and the cellular structures inside the cell membrane called organelles. In the formation of carbohydrates, the plant must allocate more storage energy to compensate for the damage, and crop yields may be reduced as a result.

In the past, ozone has been found to harm corn, soybeans, wheat, tomatoes, peanuts, lettuce and cotton in rigorous laboratory conditions. Corn, cotton, soybeans and wheat are particularly sensitive

to ozone's ability to break their molecular bonds, and a study by the University of Oregon estimated that ozone reduced the U.S. harvest by $900 million for those four crops [5].

3.2.3 Climate change driven by global warming

Yihui Ding mentioned the effect of global warming on farming. He said that because of CO2 in the atmosphere, as the concentration of it increases, the temperature increases, which will cause the crops to grow faster and shorten the cyclogeny, which would decrease the output.

What is more, He also pointed out that after climate change, the microbial decomposition of soil organic matter will accelerate, and the spread of pests and diseases, as well as the proliferation of weeds, cannot be ignored, which requires the use of more fertilizers, pesticides, and herbicides, leading to an increase in the cost of agricultural production [6].

3.2.4 Degradation of marine ecosystems

The degradation of marine ecosystems mainly affects sea farming. Phytoplankton is the major breeding object. It relies on the nutriment in the sea to grow and breed.

What is more, Species diversity in marine ecosystems is essential for the sustainable development of marine agriculture. Different kinds of organisms in the ocean depend on each other, forming a complex food chain and ecological balance and maintaining the stability of the marine ecosystem.

According to Min Jian and Xiaofeng Sun, The degradation of the Marine ecosystem makes the Marine biological community and Marine resources decrease day by day, the biological structure and proportion are unbalanced, and the living environment deteriorates gradually. Therefore, the nutriment in the sea will be lacking, and the stability of the marine ecosystem will be affected [7].

3.2.5 Hazardous substances and toxic waste

According to Chunmei Tao and Xiugang Song, due to a large amount of fertilizer application, the amount of nitrogen fertilizer is too high, and the ratio of nitrogen, phosphorus and potassium is out of whack.

Although it certainly increased production, it leads to agricultural environmental pollution. Chemical fertilizers contain harmful substances such as heavy metals, inorganic acids and organic compounds. Long-term use can directly and indirectly harm the health of plants, people and livestock. In addition, excessive dosage or improper use will also cause concentration hazards or gas hazards to crops. Long-term single use of chemical fertilizer can cause soil compaction, fertility reduction, fertilizer efficiency reduction, and soil degradation [8].

4. Some Ways to Improve the Agriculture by Using Green Chemistry

4.1. Developing and Producing Green, Non-Toxic and Harmless Agricultural Products

According to Lijun Liu, as the environment in which humans live deteriorates, we should actively apply the concepts of green chemistry to the development and production of environmentally friendly, non-toxic agricultural products in order to maintain the nutritional integrity of human diets.

Green, non-toxic, or environmentally friendly agricultural products are those that, when used and afterward, will not harm the environment or public health; they have a reasonable function and service life; they are easy to recycle, use, and regenerate; they are easy to dispose of after scrap; and they are easy to degrade in the environment. In the course of agricultural production, we should investigate, develop, and produce degradable agricultural mulching film, which can be added to the production of photosensitizers, chemical auxiliaries, etc., and which will break down into harmless substances a few months after use, thereby reducing pollution to the land and environment. This is in line with the principle of designing degradable chemicals in green chemistry. Whenever possible, non-toxic and safe raw materials should be used in the manufacturing and application of pesticides. This applies to intermediate and final products as well as to raw materials; all of them should be safe for the environment and human health [9].

4.2. New Technology for Reducing the Harm of Chemicals in Agricultural Resources

According to Lijun Liu, traditional chemistry seriously contaminates water and land resources. Some extremely poisonous compounds, such as highly toxic phosgene, hydrocyanic acid, and benzene, are still utilized as raw materials and intermediates in the synthesis of chemicals today. Production-related chemical waste is released into the environment without limitation, contaminating water supplies and soil, which has a direct impact on agriculture's foundational components. Thus, green chemistry necessitates the employment of novel techniques as well as the usage of safe and non-toxic raw materials from the source to manage and eliminate pollution sources in order to improve human health and lessen environmental pollution.

For instance, the development of cellulose and starch hydrolysis of glucose as a raw material through genetic engineering to obtain microorganisms as a catalyst, glucose into adipic acid, thereby reducing the emission of pollutants. Previously, the industrial production of adipic acid used benzene as a raw material, and benzene is known to be carcinogenic. In order to practice green chemistry, new procedures must be used, auxiliary materials must be used in reactions as little as feasible, and when they must be used, non-toxic and safe auxiliaries must be used as much as possible.

Volatile organic compounds (VOCs) are the most commonly utilized solvent in the old chemical industry, and they are more environmentally harmful. Using safe and non-toxic solvents as a substitute has grown in importance as a field of study for green chemistry. The creation of super-temporary fluids, particularly supercritical carbon dioxide as a solvent, which possesses the qualities of being non-toxic, non-combustible, and inexpensive, is the most active research project in the field of non-toxic and harmless solvent research. Under the same circumstances, it possesses both the viscosity of gases and the solubility of traditional liquid solvents. It is a solvent that is acceptable for the environment and has excellent compressibility. The ecology and land that support agricultural output will benefit from the extensive use of these superior solvents [9].

4.3. Chemical Transformation of Substance Depletion, Greenhouse Effect, Water Pollution

According to Yu Wang, the influence of green chemistry on agriculture extends beyond just ecological fertilizers. This technology can transform harmful substances into those that pose no threat to the environment or human health. For instance, acidic gases can be chemically altered through green chemistry methods. Prior to this conversion, these gases need to be appropriately prepared; typically, sulfur (S) content in the incoming acidic gases is around 2%, while chlorine (Cl) content is maintained at approximately 2.5%. Achieving the correct ratios is crucial for ensuring that subsequent desulfurization processes occur effectively and that unreacted acidic gases in the emissions are minimized post-reaction. The semi-dry method stands out as a widely utilized technique for chemical desulfurization. In this approach, lime milk is introduced into a rapid cooling tower for desulfurization. This technique not only achieves a high purification efficiency but also produces no wastewater following the reaction. Additionally, it boasts low costs, straightforward procedures, and ease of operation [10].

5. Conclusion

The present paper provides a comprehensive overview of the definitions of green chemistry and green agriculture. It primarily examines ten environmental issues, including air pollution, ozone layer depletion, climate change resulting from global warming, degradation of marine ecosystems, and the use of toxic chemicals in agriculture. Furthermore, it explores some potential solutions to these problems.

The three solutions all conform to the twelve principles of green chemistry. As for the first measure, it mainly conforms to the third, fourth and tenth points of the twelve principles. The improvement of the agricultural plastic mulching film mentioned can also decrease the by-products during the process.

The second measure mainly conforms to the first, third, fifth, eighth and tenth points of the twelve principles. For the improvement of solvent, it has been mentioned, that if the production condition can keep in normal temperature and normal pressure can be better as it can lower the use of energy.

The third measure mainly conforms to the tenth point of the twelve principles. It provides a way that if toxic substances are inevitably produced in the production process, they can be transmitted into substances that do not affect the ecological environment and human beings if it can add the technology of monitoring the toxic substance so that people can know when the toxic substances are totally transmitted.

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