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Environment and its Effects on Agricultural Production: a Study on the Impact of Global Warming

Ahmed Amer Khalil Ali, Mustafa Imad Mustafa Jaber
Department of Environmental Engineering and Pollution, Kirkuk Technical College, Northern Technical University, Kirkuk, Iraq

Abstract:

One of the biggest problems people have in the 21st century is making sure there's enough food for everyone, especially with the planet's climate and ecosystem changing at an alarming rate. The ability of plants and other creatures to grow, develop, and reproduce is severely impaired by prolonged exposure to high temperatures. The detrimental consequences of high temperatures on plant physiological processes are the primary focus of this environmental study that examines the effects of heat stress on plant development and productivity. The research demonstrates how heat stress diminishes growth, slows photosynthesis, and damages cellular structure, leading to a substantial decrease in productivity and agricultural yields. Adaptation tactics and resources are also covered in the research. Some of these tactics include enhancing agricultural practices through the use of bio- and nano- fertilizers, which boost soil health and nutrient absorption, and implementing plant breeding and improvement programs to create drought- and heat-resistant crop varieties. By combining these approaches, we can lessen the impact of climate change on farming while simultaneously increasing crop yields. Target of the article: Emphasizing the need of combining conventional and technological ways to maximize agricultural resources and guarantee sustainable production under climate change, she offers thorough insights on how to reduce the impacts of heat stress on plants.

Keywords: Food Security, Climate Conditions, Environment, Temperatures.

1. **Introduction**

Agricultural output and food security are profoundly and immediately impacted by environmental and climate conditions. Agricultural regions are particularly vulnerable to the effects of climate change, which include hotter weather overall, altered patterns of precipitation, and more frequent droughts and floods. The harvest yield is directly impacted by these occurrences. There is a direct correlation between agricultural output and food security as a result of climate change. The most vulnerable members of society feel the effects of rising food costs the most as a result of increased demand caused by falling agricultural productivity. Countries may become more dependent on food imports due to crop limitations, which leaves them exposed to volatility in world prices and hinders their capacity to attain food security. For this reason, we need long-term strategies to deal with climate change, such as creating heat-and drought-resistant farming technology, bettering the way we handle our water resources, and advocating for policies that promote sustainable agriculture [1].

With a predicted 60% rise in agricultural output over the next 40 years, the world's population is likely to skyrocket. Additionally, a lot of farmland is losing its fertility and is in bad health. The probable loss of biodiversity due to climate change has obvious long-term ramifications. The continued demand for food, fiber and feed is placing great and increasing pressure on land and water resources, the availability and productivity of which in agriculture are likely to be threatened by climate change. The increase in food prices worldwide, resulting from the increased demand for crops as raw materials and a source of energy, is a source of concern for the population [2].

Climate change, environmental pollution, and global warming expose plants to a wide range of biotic and abiotic stresses. Although there is good knowledge about how plants adapt to most or all of these individual stresses, little is known about how plants respond to a combination of these stresses, which is known as a multifactorial stressor. Recent studies have revealed that an increase in the number of multifactorial stressors that occur simultaneously causes a significant decline in plant growth, production, and survival, and also has a significant and direct impact on the biological diversity on which plants depend for their growth and development. This impact should be a sign of a severe and direct warning to our society that pushes researchers to act quickly and decisively to limit or reduce environmental pollutants, combat global warming and work to increase the ability of plants to withstand multifactorial stress groups, which is reflected in increased production and food sufficiency [3].

The cumulative impact of human life on planet Earth over the past decades, especially the industrial revolution, has led to a continued increase in the production of gases that cause global warming, such as CO2, which is produced by burning fossil fuels. The accumulation of this gas in the atmosphere works to trap infrared radiation that is emitted from the Earth’s surface after absorbing sunlight, which works to heat the planet. The monthly average calculated for carbon dioxide, which was measured at the Mauna Loa Observatory in Hawaii, constitutes the longest record of direct measurements of carbon dioxide in the atmosphere (see Figures 1).

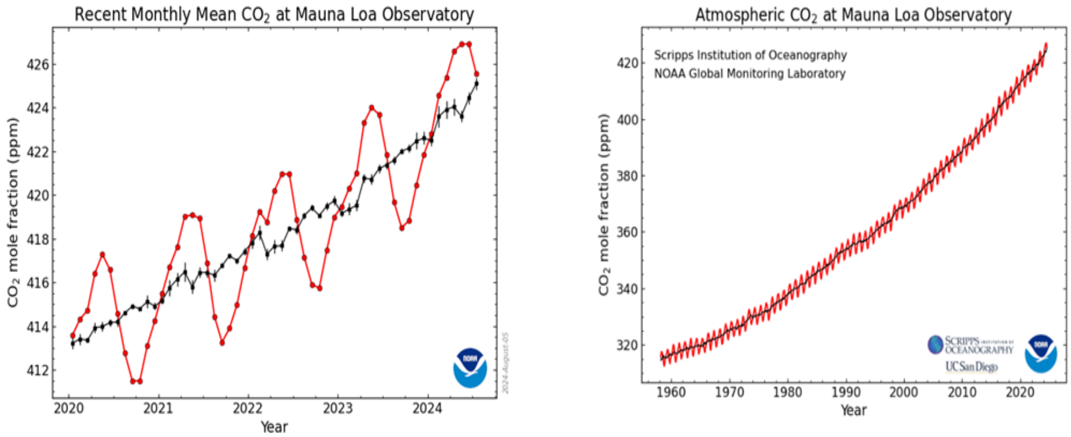

Figure 1. Called Keeling curves. Data were retrieved from NOAA's Global Monitoring website https://gml.noaa.gov/ccgg/trends and accessed on August 5, 2024.

This raises concerns about the continued increase in temperatures, known as global warming, which plays a direct and radical role in changing the climate, accompanied by a significant increase in temperatures and drought, as well as the frequent coincidence with the presence of other non-biotic stress conditions such as salinity and degradation of agricultural soils. In addition, the large and rapid increase in the world's population, which coincides with the expansion of land use for housing and commercial purposes, leads to a decrease in the availability of arable agricultural land, the loss of which leads to the necessity of working to increase the agricultural yield produced from every part of the remaining agricultural land in order to provide food for the ever-increasing number of people in the world [4-6].

2. Environmental Factors Affecting Plant Production

The cumulative impact of human life on planet Earth over the past several decades has introduced many extreme and harsh environmental conditions into ecosystems and lands. These extreme and volatile environmental events resulting from climate change include heat waves, cold, floods, and persistent drought, as well as extreme soil conditions such as saline, alkaline, and acidic soil conditions. They also include various pollutants made by humans such as plastics, heavy metals, antibiotics, pesticides, and organic pollutants, radiation such as ultraviolet rays, the availability of limited nutrients, airborne particles, and high levels of toxic gases such as ozone, carbon dioxide, and combustion products, in addition to the direct impact on plant growth and reproduction within many agricultural ecosystems. It has also been proven that some environmental conditions have been proven to increase the exposure of some plants to attack by pathogens or various insects [7-9].

3. How Temperature Affects Crop Quality and Productivity

Temperature is one of the most important factors that control plant growth and development, and the entire life cycle of plants is affected by temperature, as plants usually grow rapidly and show specific behavior and changes in shape under moderate and medium temperature conditions. This response is called thermogenesis, and when exposed to humid or cold temperatures, the flowering process and germination process are stimulated in some types of plants. Interestingly, once some plants that grow in moderate temperatures are exposed to low temperatures for a period, they can acquire the ability to resist freezing stress, and this process is called cold acclimatization. One persistent problem that has arisen as a result of the rapid climatic change is heat stress, which has a deleterious effect on plant development and growth [10].

When soil temperature changes, it affects the soil's moisture content, water retention capacity, and particle size. When soil temperatures rise, water moves less freely through the soil and more quickly evaporates [11]. The rate of plant growth, flowering and development depends largely on the temperature surrounding the plants. Each plant has three types of temperatures that affect its growth: the optimum temperature, which means the temperature that achieves maximum growth and productivity for the plant, as this temperature provides the ideal conditions for the activity of vital processes such as respiration, photosynthesis, and the transfer of nutrients. Many plants have optimum temperatures between 20 and 25 degrees Celsius. The second temperature that affects plant growth is the maximum temperature, which means the highest temperature that the plant can tolerate without significantly affecting its health. Very high temperatures may expose the plant to heat stress, which leads to a decrease in the rate of photosynthesis, wilting of leaves, or cell death. In some plants, such as tomatoes, they may begin to be affected when temperatures exceed 35 degrees Celsius. Another degree that affects plant growth and development is the minimum temperature, which is the lowest temperature that the plant can tolerate without being exposed to severe damage, and its effect can lead to freezing of plant tissues, causing permanent damage to the plant. Some plants may be negatively affected at temperatures below 5°C, while other plants may be able to tolerate much lower temperatures [12,13].

The rapid growth of non-perennial plants leads to a shorter growth cycle, which leads to smaller plants, shorter reproductive periods, and lower production potential. Extreme temperatures above or below a certain threshold at a critical time during growth can have a significant impact on production. Soybeans, which are photoperiod-sensitive plants, can react to temperature, causing a disruption in their phenological development, and very high temperatures during flowering periods affect the ability of pollen grains to grow, fertilize, and form fruits or grains [14].

High temperature stress occurs when temperatures exceed a certain threshold for a specific period. This stress causes significant impairment to plant growth and development, and the effect may be irreversible. When the temperature rises by 10 to 15 °C above the ambient temperature of the plant for a short period, it is called heat stress or heat shock (HT). This type of stress is considered abiotic and is a major cause of reduced crop yields[15].

HT causes negative effects on plants, such as protein degradation, inhibition of protein synthesis, degradation, and alteration of the fluidity and integrity of lipid membranes. Globally, many crops are susceptible to high temperature stress, which ultimately has a negative impact on the economies of countries due to reduced crop production [16,17].

4. Heat Stress and Its Effects on Crop Loss

There is a strong correlation between climate change and agricultural output; research has demonstrated that global warming significantly affects agriculture in multiple ways, including changes in the frequency and severity of weather extremes. Factors that directly affect agriculture include the ability to forecast extreme weather events like heat waves, droughts, and floods; changes in diseases and pests; increased atmospheric and ground-level carbon dioxide concentrations; and changes in food quality [18,19].

Among the most significant factors influencing Earth's climate, global warming is the steady rise in the average surface temperature over the course of a given year. One of the most influential environmental factors on plant development, growth, and production is temperature. Stress from prolonged exposure to temperatures too high or too low can cause plants to suffer stunted growth, stunted flower and fruit development, drastically reduced yields, or even death. Extreme heat events can be classified based on the maximum temperatures recorded (intensity), the frequency of occurrence (frequency), and the duration (duration). Extreme heat events and prolonged heat events (global warming) require real and effective strategies from breeders to meet the food security needs of farmers and consumers. Risk assessment in agricultural production and food security also requires consideration of several aspects such as the severity of the adverse event, the frequency with which sustained temperatures are exceeded during the growing season, and whether and how long heat events exceed lethal temperatures for plants. As the global warming scenario continues, identifying temperature thresholds for important crops and their impact on agricultural production is vital and important for anticipating risks to food security [20-24].

Crop productivity depends on several factors such as efficient reproduction, photosynthetic efficiency, resource allocation, and plant structure, all of which are sensitive to heat stress. Several studies have shown that the effects of heat stress vary among crops, species, and cultivars. In general, plants grown in temperate regions are more susceptible to heat stress than those grown in tropical regions. Some research on diverse crops such as cereals, horticultural crops, and legumes has shown that heat stress significantly affects winter crops such as wheat, as well as warm season crops such as tomato, maize, rice, and legumes during the vegetative stage. This stress leads to reduced crop productivity through its direct effect on enzymes and tissues, impaired flowering, and oxidative stress in the reproductive stage. Moreover, the reproductive stage of crops such as rice, tomato, cotton, maize, and soybean are more vulnerable to heat stress, as high temperatures during the inflorescence, spike or flowering stage can lead to decreased crop fertility and sometimes even flower abortion [25,26].

Global warming will eventually raise the average temperature and will have negative effects on the yield of horticultural and cereal crops, so it is necessary to identify the effects that occur in plants during high heat stress in order to improve adaptation methods to compensate for the potential damage to the crop because it is believed that temperature fluctuations will continue to be more negative during the next thirty years. Plants typically grow within a certain temperature range. If temperatures are too high or too low, production can be at risk. Rising temperatures are expected to negatively impact crop yields. Regional temperature changes may be easier to predict through weather forecasts than rainfall. Meteorological data show that average annual temperatures in areas where staple crops such as barley, wheat, rice, soybeans, and maize are grown have risen by 1°C over the past century. This increase may have negative effects on production in vulnerable areas and may cause water scarcity due to loss of surface water and increased demand for groundwater. Between 1990 and 2000, the temperature rose by 0.6°C, and the world is expected to see an average annual temperature increase of 2.5°C to 4.3°C by 2080 due to greenhouse gases. This climate change could reduce crop production due to extreme heat and irregular rainfall. For example, studies have shown a 38% decrease in canola and 39% in camelina due to heat. As for wheat, a one degree increase in average temperature could reduce wheat production by 2.6% in China. On the other hand, a 1°C increase in global temperatures could reduce rice yields by 3.2%, wheat by 4%–6%, soybeans by 3.1%, and corn by 7.4%. The yields of other crops such as millet, legumes, and rapeseed oil are also significantly affected by a 1°C increase in global temperature. On the other hand, crop yields such as oats and potatoes are lower with a 1°C increase in temperature (see Figure 2). The world population is expected to reach 9 billion by 2050, which requires increasing agricultural production by 70% despite the negative impacts of climate change on crops [27-29].

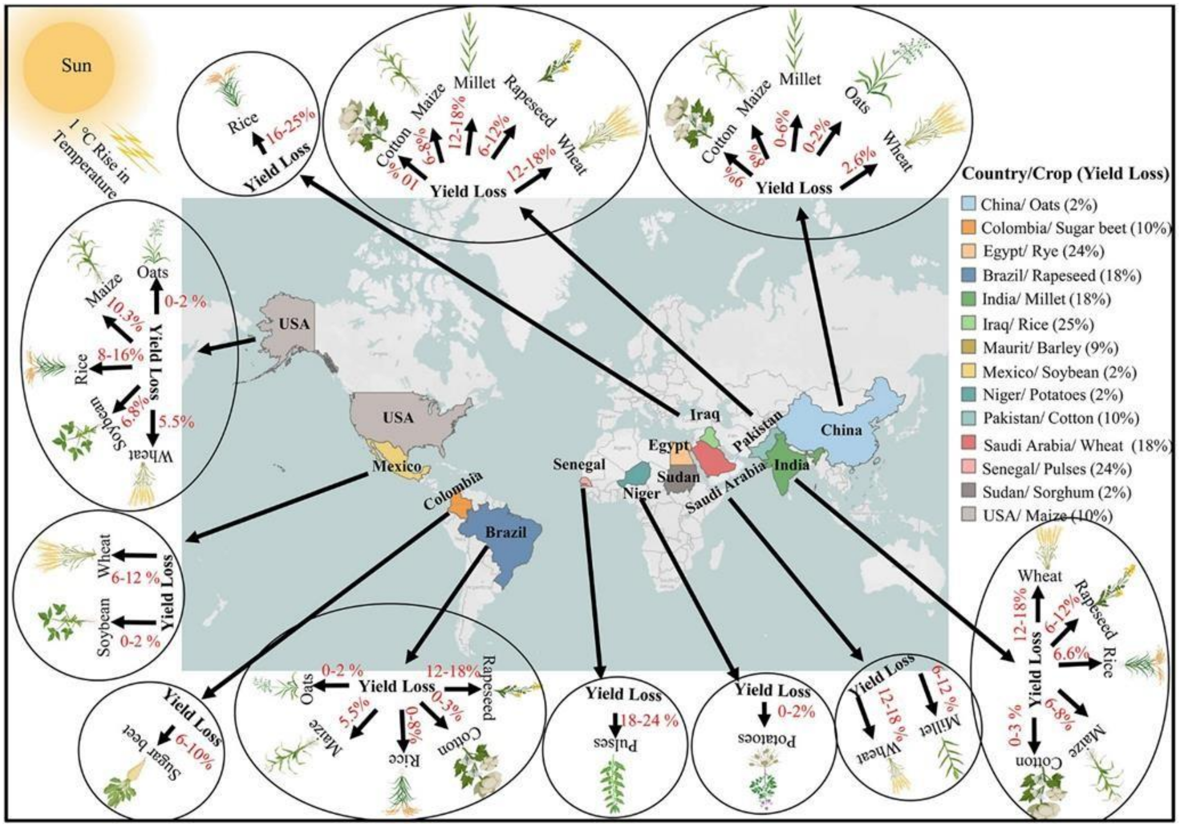

Figure 2. A one-degree Celsius increase in temperature has an impact on the productivity of strategic crops in different countries around the world. The different colors of the countries shown on the map show the highest decline in crop productivity in one country [30].

Global food production over the past century has shifted from using 2500 different plant species to relying on four major crops: wheat, rice, soybeans, and maize [31].

Although legumes account for about 33% of human dietary protein needs, these crops account for almost two-thirds of human consumption globally. Both food safety and ecological preservation are affected by this [32].

If we continue to depend on just a few of crops, we risk making ourselves economically and politically vulnerable due to climate change and other causes. So, to keep the world's food supply stable, it may be vital to determine how increasing temperatures would affect the harvest of staple crops [33].

5. Modern Techniques of Fertilizers and Stimulants to Improve Plant Resilience

Global climate changes including drought and high temperatures are among the main factors causing soil desertification and low crop productivity. In this context, bio stimulants can play an important role in reducing the negative effects of these stresses on plants by stimulating protection and tolerance mechanisms in plants such as physiological, chemical, anatomical, biological and molecular changes. In addition, they stimulate plant immune responses to various biotic stresses by deposition of callus, spreading hypersensitivity and synthesis of lignin [34,35].

The addition of conventional chemical fertilizers is the main cause of global CO2 emissions estimated at 500 tons/year. Even though it uses animal husbandry waste as its main ingredient, organic fertilizer production does add to gas emissions in some way. Use of biofertilizers, novel soil amendments, and nanofertilizers is the most promising alternative that is presently being researched [36].

By enhancing the efficiency of traditional fertilizers with nanotechnology, a new kind of fertilizer has emerged: nano fertilizers. Fertilizers with nanoscale dimensions are made of organic or mineral components that have been shrunk to sizes in the nanometer range (1 nanometer = 1 billionth of a meter). Nano fertilizers have a number of benefits over their larger counterparts, one of which being improved nutrient uptake by plants and soil due to the smaller particle size. Because nano fertilizers can transport nutrients more efficiently, they increase the efficacy of fertilizers while decreasing the amount of fertilizer required. Nano fertilizers have the added bonus of lowering mineral loss, which is a major concern for the environment because nutrients may easily evaporate or drain out the soil. Nano fertilizers have the potential to improve nutrient availability, which in turn improves plant health and growth, which is another beneficial impact. Because nutrient release may be more precisely controlled, it is possible to tailor doses to individual plants' needs, which is an additional advantage. Nano fertilizers have many potential benefits, but there are also certain drawbacks that must be thoroughly investigated [37,38]. These include high manufacturing costs and the possibility of long- term health and environmental repercussions.

To enhance soil health and boost crop output in an eco-friendly manner, biofertilizers are used. These fertilizers include living organisms or their byproducts. Biofertilizers are an alternative to chemical fertilizers that boost soil fertility and plant growth through biological processes. Beneficial microorganisms, such as fungus and bacteria, that stimulate plant growth are one kind of biofertilizer. Soil bacteria like rhizobia can fix nitrogen and make it available to plants, while mycorrhizae fungus help plants absorb nutrients better. Insoluble phosphorus can be transformed into an absorbable form by plants with the help of fertilizers that contain phosphorus bacteria. These fertilizers are another kind of biofertilizer. Also included are organic fertilizers, which include compost and manure, and which boost soil biology by containing organic elements. Compost tea and organic extracts are examples of fertilizers that contain breakdown products; these fertilizers include biodegradable nutrients and boost soil microbial activity. Any kind of microbe—bacteria or fungi—that interacts with plants in a way that boosts their immune systems is considered a plant growth promoting microorganism (PGPM). Microbes that promote plant development also boost plant health by increasing nutrient absorption and strengthening plant defenses against diseases. As a result, crop yields are increased and plants are kept in better condition. Because biofertilizers improve soil structure and increase organic matter content, which boosts soil water and nutrient retention, this is one of the most significant advantages of biofertilizers. Because biofertilizers boost biological activity, which in turn improves the soil's nutrient utilization efficiency, this is another benefit. Additionally, biofertilizers can lessen the need for chemical fertilizers, which in turn minimizes chemical fertilizers' harmful effects on the environment. Another benefit is supporting plant growth as it helps in enhancing plant growth and improving its health, which leads to improving productivity and quality. The work and performance of biofertilizers can be improved by combining them with soil amendments that have positive properties to improve soil properties, pH, CE, and water holding capacity [36,39,40,41].

One of the natural soil improvers that have been worked on and developed recently, biochar has emerged and has received attention because it is produced through thermal decomposition as well as the conversion of removable biomass into gas, and it has the advantage that it does not produce large amounts of carbon dioxide gas, on the other hand, once it enters the soil, it works to greatly increase the soil's ability to retain carbon dioxide gas. Among its other properties, it has high porosity as well as a high absorption capacity towards nutrients and water. It has been recently indicated in corn and wheat that biochar activated with PGPMs enhances soil microbial diversity as well as the mutual interaction between soil and plant, which leads to better physiological parameters. The importance of all these new technologies is to improve plant nutrition and health, especially considering global warming, which is of great importance. Fahmy learned about increasing the natural resilience of plants against biotic and abiotic climate indicators by stimulating the plant's immune system and enhancing the soil's ability to retain water. This exposes the plant to low water stress, which leads to a slow release of nutrients that makes them widely available to the plant [42,43].

6. Breeding and Improvement Programs are an Effective Solution to Confront the Decline in Plant Production Resulting from Global Warming

Plant breeding and improvement aims to be the main player in mitigating the negative effects of global warming. It has been used within the strategies of the Green Revolution as a means used to enhance crop production by hybridizing plants with smaller versions that have harder stems than other common crops, and farmers have effectively used these methods along with other methods of efficient and improved irrigation, effective fertilizers, and strong pesticides [44].

The collaboration between designers as well as biologists, breeders, and farmers to accommodate environmental changes and improve sustainability clearly reflects the philosophy of comprehensive planning necessary to overcome all the challenges of global warming. Despite the significant and continuous progress in plant science and the biophysical and abiotic mechanisms of global warming and rising temperatures, only a few technologies have been achieved to date that led to maintaining crop productivity, growth, and development considering rising temperatures and responding to the resulting economic and social challenges. It has been pointed out that breeding programs can take more than 30 years from the laboratory to the table and although genomic technology has helped to reduce the gap in this time frame, the time lag between discovery and application is still very long [45].

On the other hand, molecular and non-molecular genetic breeding, and improvement programs, engineered or not, often address individual traits such as resistance to certain pathogens or pests, but they are still weak in dealing with some traits, especially complex traits such as tolerance to high temperatures. Therefore, to address the challenge of global climate conditions, there is a need for a multi-faceted and comprehensive approach where crop production is viewed from one side of the resilience of the agricultural ecosystem. The current view of the agricultural ecosystem on the one hand and the crops on the other hand and the new technologies available now are mandatory to shape more resilient and adaptable crops. The entire food chain, from the discovery of new varieties to their introduction to the market, requires precise distribution systems and appropriate operations, which requires advanced management and marketing capabilities. This entire chain that has implications for future developments has been termed the BDA. Adaptation to global warming and temperature-related stresses is certainly dependent on existing strategies that include knowledge on how to deal with food security in both developing and developed countries. In this regard, the recent successes achieved in many African countries, the so-called African Green Revolution, are at risk of being undone or halted due to the lack of strategies to help farmers overcome the problems posed by global warming [46,47]. Genetic core dissections focusing on important agronomic traits, such as grain size, flowering timing, pathogen resistance and fiber quality, pave the way for the application of new breeding techniques (NBTs) in breeding programmers and the exploitation of genetic resources found through next- generation sequencing (NGS). Furthermore, plant phenotyping is a link between two fundamental approaches used to produce sustainable food security in breeding programmers and precision agriculture, both of which are under controlled conditions [45,48,49,50].

Identified four challenges when addressing the threats posed by climate change to global food security: changing the culture of research; finding economic options for farmers, communities, and countries; ensuring options that are relevant to the factors most affected by climate change; and combining strategies such as mitigation and adaptation. Solutions to climate change in smart societies, and farming systems that practice conservation agriculture in developed countries are also seen as enabling more resilient and sustainable agriculture and are well suited to the circular economy vision.

Conclusion

Global warming is a major environmental challenge that negatively impacts agriculture by increasing temperatures, changing rainfall patterns, and increasing climate change, leading to reduced crop yields, increased disease, and deterioration in product quality. Nano- and bio-fertilizer technologies offer great potential for improving plant productivity. Nano-fertilizers enhance nutrient uptake more efficiently due to their small size, while bio-fertilizers contain microorganisms that improve soil health and deliver nutrients more efficiently. Plant breeding and improvement technologies also play an important role. By improving plant resistance to harsh conditions such as drought and high temperatures, the negative impact of climate change can be reduced. These technologies include genetic engineering and conventional breeding to develop plant varieties that are more adaptable to the changing environment.

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