Climate-smart Agriculture

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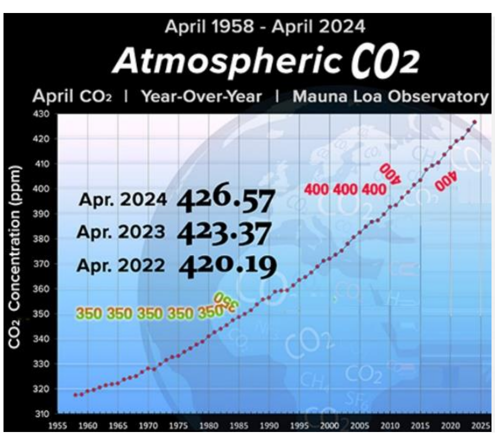
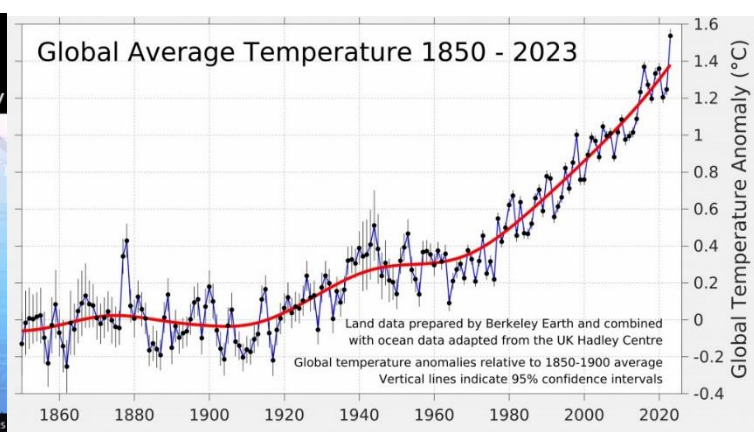
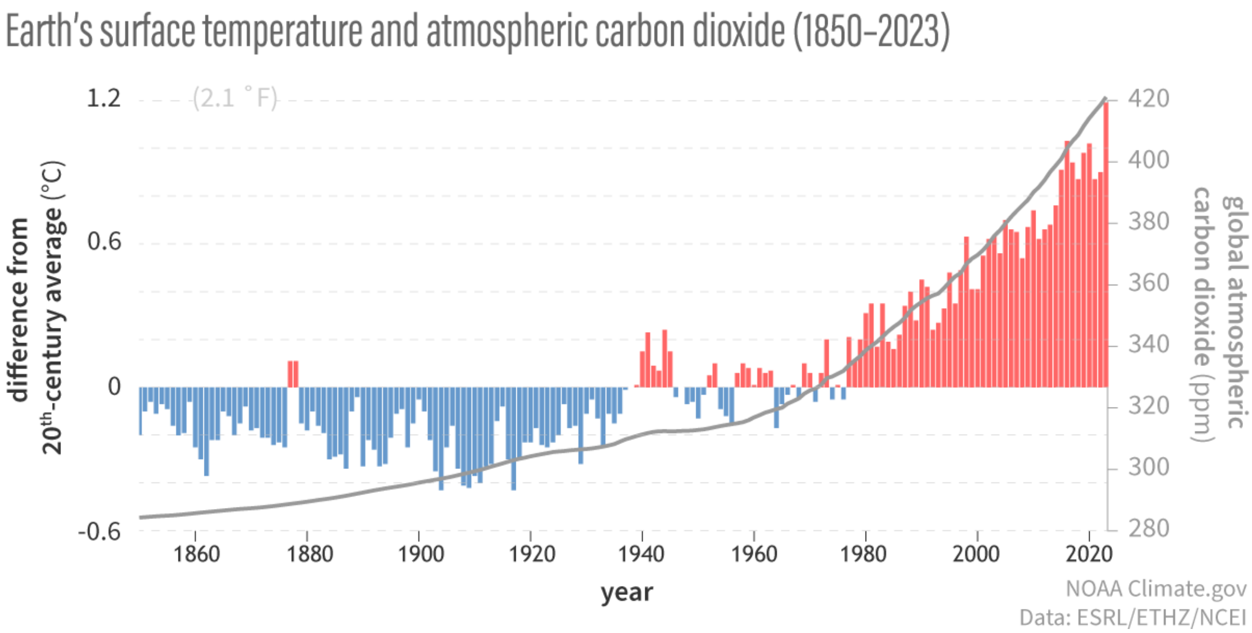
1. Causes and signs of climate change

Climate change refers to long-term shifts in temperature and weather patterns. Human activities have been the main driver of the presently ongoing climate change, primarily due to the burning of fossil fuels like coal, oil and gas. The fifth assessment report released in 2013 from the Intergovernmental Panel on Climate Change (IPCC) stated that “Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased” [1]. A decade later in the sixth assessment report (Climate Change 2023: Synthesis Report) IPCC further predicted that “Human activities, principally through emissions of greenhouse gases, have unequivocally caused global warming, with global surface temperature reaching 1.1°C above 1850–1900 in 2011–2020. Global greenhouse gas emissions have continued to increase, with unequal historical and ongoing contributions arising from unsustainable energy use, land use and land-use change, lifestyles and patterns of consumption and production across regions, between and within countries, and among individuals. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred. Human-caused climate change is already affecting many weather and climate extremes in every region across the globe. This has led to widespread adverse impacts and related losses and damages to nature and people. Continued greenhouse gas emissions will lead to increasing global warming, with the best estimate of reaching 1.5°C in the near term in considered scenarios and modelled pathways. Every increment of global warming will intensify multiple and concurrent hazards” [2].





Indeed, the atmospheric CO_2 concentration has been elevated from the 280 ppm preindustrial level to the present over 420 ppm mainly due to fossil fuel consumption [3], as accompanied with the global surface average temperature increase by 1.36°C (by 2.45°F to 59.0°F in 2023) during the same period [4]. The Earth's surface has been successively warmer in the past four decades, showing an increasing temperature higher than any preceding decade since 1850 [2]. Therefore, scientists are mostly confident (i.e., >95% probability) that global warming is occurring and humans are responsible for at least half of the temperature increase in the last 50 years [1]. The Earth's climate system has been changing as a result of the ongoing increases in the atmospheric CO_2 concentration and the global average surface temperature. Other climate change signs include the experiencing decreases of the Arctic sea ice, the Northern Hemisphere snowfall, and the global glacier coverage and the experiencing increases in sea surface temperature, ocean heat content, air humidity, and frequency & severity of extreme weathers [5].



2. Climate change and agriculture

Modern agriculture contributes significantly to climate change while being significantly impacted by its consequences. That is to say, agriculture is a prime driver and the first victim of climate change.

It has been scientifically estimated that 12% of global annual greenhouse gas (GHG) emissions (7.1 Gt CO_2 equivalent) is from the agricultural sector. Of the total agricultural emissions, carbon dioxide, nitrous oxide, and methane account for 18%, 28%, and 54%, respectively [6].

Climate change is long-term and hidden by year-to-year variability. Changes in temperature, atmospheric CO_2, and the frequency and intensity of extreme weather could, however, have significant impacts on crop yields. Increases in temperature and carbon dioxide (CO_2) can increase some crop yields in some places with meeting the mandatorily elevated nutrient levels, soil moisture, water availability, and other conditions. Changes in the frequency and severity of droughts and floods could pose challenges for farmers and ranchers and threaten food safety. Heat stress from increasing heat waves restricts plant growth, reduces crop yields, and damages livestock and human health. Warmer water temperatures are likely to cause the habitat ranges of many fish and shellfish species to shift, which could disrupt ecosystems. Warmer winters increase pest threats to agriculture. Increased freeze risks from climate change in particular late spring frosts also form a major threat to agriculture.

Climate change is set to reshape local crop choices in the long run. Different crops demonstrate distinct optimal temperature for growth and reproduction. In some areas, warming may benefit the types of crops that are typically planted there, or allow farmers to shift to crops that are currently grown in warmer areas. In other areas, crop yields will decline if the higher temperature exceeds the optimum temperatures. For grain crops, a higher growing-season temperature typically results in faster growth, which accelerates grain filling: the movement of sugars within the plant to grain. Faster grain filling means less time for photosynthesis during this period, leading to lower yields since less sugar is available for grain. Higher temperatures also reduce pollination success and accelerate crop water use, while benefiting weeds and pests, which flourish in warmer environments, then migrate. An elevated CO_2 level can increase plant growth. However, other factors, such as changing temperatures, ozone, and water and nutrient constraints, may counteract these potential increases in yield. If temperature exceeds a crop's optimal level, or sufficient water and nutrients are not available, for example, yield increases may be reduced or reversed. Research has shown that elevated CO_2 was associated with reduced protein and nitrogen content in alfalfa and soybean plants, resulting in a loss of quality. Reduced grain and forage quality can reduce the ability of pasture and rangeland to support grazing livestock. More extreme temperature and precipitation can prevent crops from growing. Extreme events, especially floods and droughts, can harm crops and reduce yields. Many weeds, pests, and fungi thrive under warmer temperatures, wetter climates, and increased CO_2 levels. This could cause new problems for farmers' crops previously unexposed to these species. Though rising CO_2 can stimulate plant growth, it also reduces the nutritional value of most food crops. This direct effect of rising CO_2 on the nutritional value of crops represents a potential threat to human health. Human health is also threatened by increased pesticide use due to increased pest pressures and reductions in the efficacy of pesticides.

Plant pests and diseases are unpredictable in climate change, crossing borders and interacting with extreme weather events such as droughts, escalating the risk of global spread [7]. Our knowledge of adapting plants to disease and pest pressures in a changing climate has significant gaps. We lack comprehensive insights into how climate variables, such as temperature shifts, altered precipitation, or increased CO_2 levels, affect the behavior of pathogens and pests and how their combined interactions affect plants [8–10].

Changes in climate could affect animals both directly and indirectly. Heat waves, for example, which are projected to increase under climate change, could directly threaten livestock. Heat stress affects animals both directly and indirectly. Over time, heat stress can increase vulnerability to disease, reduce fertility, and reduce milk production.

Overall, climate change could make it more difficult to grow crops, raise animals, and catch fish in the same ways and same places as we have done in the past. In the U.S., changing rainfall and temperature patterns are already affecting farmer decisions and patterns of productivity. Changes in climate patterns observed in the Midwest already include longer growing seasons, more frequent extreme weather events, and significant increases in nighttime temperatures. The less frequent but more intense rainfall patterns engender a greater risk of summer drought and an increased risk of intense precipitation and seasonal flooding in the Midwest. This can delay crop planting, increase plant diseases, retard plant growth, and cause flooding, runoff, and erosion–all of which affect crop yields and exacerbate the loss of nutrients and soil to the environment.

3. Climate-smart agriculture

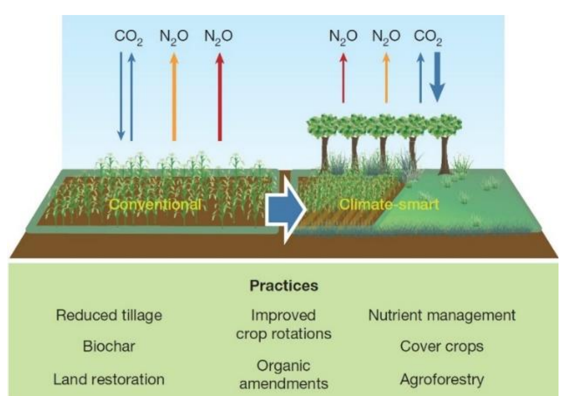
Climate-smart agriculture (CSA) refers to a set of farming methods designed to enhance the productivity and resilience of agricultural production systems that have been affected by climate change. It is an integrated, holistic approach for managing cropland, livestock, forests, and fisheries to achieve the three main goals: Sustain and increase productivity and yield, enhance resilience to environmental changes, and reduce greenhouse gas emissions.

Climate-smart agriculture was first defined in a 2010 report by The Food and Agriculture Organization (FAO) of the United Nations as "an approach that helps guide actions to transform agricultural production systems towards green and climate resilient practices." [11]. It is an approach transforming and reorienting agricultural systems to support food security under the new realities of climate change. It addresses the risks that climate change poses to agriculture. It combines various sustainable methods to tackle the climate challenges of a specific farming community. Climate-smart agriculture aims to simultaneously achieve three outcomes:

1) **Increased productivity** (sustainably intensifying agriculture): Produce more and better food to improve nutrition security and boost incomes.
2) **Enhanced resilience** (adapting to climate change): Reduce vulnerability to drought, pests, diseases and other climate-related risks and shocks; and improve capacity to adapt and grow in the face of longer-term stresses like shortened seasons and erratic weather patterns.
3) **Reduced emissions** (mitigating greenhouse gas emissions): Pursue lower emissions for each calorie or kilo of food produced, avoid deforestation from agriculture and identify ways to absorb carbon out of the atmosphere.

Climate-smart agriculture practices are exemplified as follows:

(1) Conservation tillage
(2) Crop rotation
(3) Cover cropping
(4) Crop selection and diversification
(5) Rotational grazing
(6) Use of high tunnels
(7) Enhancing soil health to increase crop productivity, C sequestration, and resilience to drought and flooding
(8) Improved pest, water, and nutrient management
(9) Improved grassland and forestry management



(10) Improved manure management using anaerobic digesters
(11) Integrated crop, livestock, aquaculture and agroforestry systems
(12) Restoring degraded land

Optimizing agricultural systems for climate adaptation and mitigation requires shifting focus from maximizing productivity to optimizing it across diverse landscapes and socioeconomic contexts to develop strategies that reduce GHG emissions while enhancing soil health, carbon sequestration, crop adaptation, biodiversity, and other ecosystem services.

The adaptation strategies and practices implemented on individual farms are not going to be "one-size-fits-all" and must be tailored to specific farm production systems. Adaptation strategies will vary by commodity such as field crops perennial fruit crops, vegetables and horticulture crops, dairy and livestock, agroforestry and maple products, and aquaculture. Crosscutting strategies: improve soil drainage for crops, improve soil's ability to retain moisture to adapt to periods of drought; install supplemental cooling and change work patterns to reduce heat stress, and use new programs, plant varieties and updated planning tools to contend with increased pests.

An important prerequisite for the development and adoption of sustainable agricultural practices and technologies over large geographic domains, as well as the sustainable utilization of certain resources (e.g., soil and water), is producer participation. Participatory approaches and a circular flow of information are recognized to provide social benefits as new technologies and practices are learned directly and then adapted to agroecological, social, and economic circumstances. Implementation of CSA practices may require that farmers have access to specific inputs, such as tree seedlings, seeds or fertilizers. Lack of such inputs constrains widespread adoption.

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