Name

Professor

Institutional affiliations

Course

Date

**Abstract**

Some authorities have claimed that global warming is one of the most—if not the most—important public health threat of this century. They do not, however, support this assertion by comparative analysis of the relative magnitude and severity of various health threats. Such an analysis, presented here, shows that other global health threats outrank global warming at present, and are likely to continue to do so through the foreseeable future, even under the warmest scenario developed by the UN Intergovernmental Panel on Climate Change (IPCC). Exaggerated and unsupported claims about the importance of global warming risk skewing the world’s public health priorities away from real, urgent health problems. Policies curbing global warming would, moreover, increase energy prices and reduce its usage, retarding both economic development and advances in human wellbeing. That would slow advances in society’s adaptive capacity to deal not only with the effects of global warming, but all other sources of adversity. Through the foreseeable future, global health would be advanced farther, faster, more surely, and more economically if efforts are focused not on reducing greenhouse gas emissions, but on reducing vulnerability to today’s urgent health problems that may be exacerbated by global warming, while increasing adaptive capacity, particularly of developing countries, through economic development. Introduction Several influential policymakers have declared that climate change is one of the defining challenges of this century. In their wake, even august publications such as have taken the position that “climate change is the biggest global health threat of the 21st century.” Such assertions have serious implications for allocation of fiscal and human resources to address global public health problems. Societal resources devoted to curb carbon dioxide and other greenhouse gas emissions will be unavailable for other—and as will be shown—more urgent tasks including vector control, developing safer water supplies or installing sanitation facilities in developing countries, or for cancer research or drug development in developed countries. Additionally, reduction in wealth due to higher energy costs and lower energy usage could have serious consequences, not only for society’s public health, but also for its continued ability to adapt to present or future health threats (Goklany, I. M. (2009). Global health threats: global warming in perspective. The Lancet, 1(2), 3.).

Global warming, an escalating consequence of anthropogenic activities, presents a multifaceted threat to the planet's ecosystems, societies, and economies. This comprehensive abstract delves into the intricate dynamics and pervasive impacts of global warming, elucidating its far-reaching consequences and urgent implications for global sustainability.

At its core, global warming stems from the relentless emission of greenhouse gases, primarily carbon dioxide, into the atmosphere through human activities such as fossil fuel combustion, deforestation, and industrial processes. This influx of greenhouse gases traps heat within the Earth's atmosphere, causing a gradual rise in average temperatures across the globe. The ramifications of this temperature increase extend across various domains, profoundly altering weather patterns, exacerbating extreme weather events, and destabilizing ecosystems.

One of the most pressing manifestations of global warming is the rise in sea levels, driven by the melting of polar ice caps and glaciers. Coastal regions face imminent threats of inundation, erosion, and saltwater intrusion, imperiling communities, habitats, and infrastructure. Furthermore, global warming intensifies the frequency and severity of extreme weather events, including heatwaves, droughts, floods, and storms, amplifying risks to human health, livelihoods, and food security.

Ecosystems, critical for maintaining biodiversity and ecological balance, confront unprecedented disruptions as a consequence of global warming-induced climate change. Shifts in temperature and precipitation regimes trigger habitat loss, species extinction, and ecosystem degradation, compromising essential ecosystem services and undermining human well-being. Additionally, global warming exacerbates existing environmental stressors, such as deforestation, pollution, and habitat fragmentation, exacerbating vulnerabilities and diminishing resilience.

Societies worldwide grapple with the socio-economic ramifications of global warming, exacerbating inequalities and exacerbating vulnerabilities. Marginalized communities bear the brunt of climate-related risks, facing challenges in adapting to changing climatic conditions and accessing essential resources. Furthermore, global warming amplifies existing disparities, exacerbating poverty, food insecurity, and social unrest, particularly in developing regions with limited adaptive capacity.

Mitigating the threat of global warming necessitates concerted efforts to reduce greenhouse gas emissions, enhance adaptive capacity, and foster sustainable development pathways. By prioritizing renewable energy, transitioning to low-carbon economies, and implementing climate-resilient policies, humanity can mitigate the adverse impacts of global warming and safeguard the planet for future generations. Moreover, equitable and inclusive strategies are imperative to address the differential impacts of global warming and ensure the resilience of vulnerable communities.

In conclusion, global warming poses an existential threat to the planet, demanding urgent and decisive action on local, national, and global scales. By recognizing the interconnectedness of environmental, social, and economic systems, humanity can navigate towards a sustainable future characterized by resilience, equity, and prosperity. Embracing the imperative of climate action offers a pathway towards safeguarding the planet's ecosystems, enhancing human well-being, and securing a thriving future for all.

This article is going to focus on global warming as a worldwide threat.

Flooding Bangladesh: One of the poorest nations in the world is projected to lose 17.5% of its land if sea level rises about 40 inches (1 m). Tens of thousands of people are likely to be displaced, and the country’s agricultural system will be adversely affected. Coastal flooding will threaten animals, plants, and fresh water supplies. The current danger posed by storm surges when cyclones hit Bangladesh is likely to increase. Disappearing Islands: The Majuro Atoll in the Pacific Marshall Islands is projected to lose 80% of its land with a 20- inch (0.5m) rise in sea level. Many of the islands will simply disappear under the rising seas. A similar fate awaits other islands throughout the South Pacific and Indian Oceans, including many in the Maldives and French Polynesia. Coral reefs, which protect many of these islands, will be submerged, subjecting the local peoples to heightened storm surges and disrupted coastal ecosystems. Tourism and local agriculture will be severely challenged. Disappearing Ice Packs: Wildlife in the arctic regions will be seriously affected as warmer temperatures affect the ocean ice cover. Polar bears rely on sea ice to hunt seals, which use the ice for rearing their young. The native peoples also rely on the ice to hunt these species and walruses. Observations of walrus in 1996-99 showed them to be thin and in poor condition, partly due to receding sea ice. Health and Disease: Cold winter weather reduces the spread of infectious diseases by killing infectious organisms and carrier species, such as mosquitoes. Warmer, wetter weather could increase the spread of malaria, dengue fever, and yellow fever. The possible increase in flooding and damage to water and sewage infrastructure can further encourage the spread of disease. Increased Air Pollution: Three out of four of the world’s highestdensity cities are in rapidly developing countries, where vehicle pollution is high. In Central Europe alone 21,000 deaths are tied to air pollution each year. The concentration of photochemical pollutants, such as ozone, tends to increase with warmer temperatures. Ozone damages lung tissue and is especially harmful to people with asthma and other lung conditions. Impacting Ecosystems: More importantly, perhaps, global warming is already putting pressure on ecosystems, the plants and animals that co-exist in a particular climate zone, both on land and in the ocean. Warmer temperatures have already shifted the growing season in many parts of the globe. The growing season in parts of the Northern Hemisphere became two weeks longer in the second half of the 20th century. Spring is coming earlier in both hemispheres. This change in the growing season affects the broader ecosystem. Migrating animals have to start seeking food sources earlier. The shift in seasons may already be causing the lifecycles of pollinators, like bees, to be out of synch with flowering plants and trees10. This mismatch can limit the ability of both pollinators and plants to survive and reproduce, which would reduce food availability throughout the food chain. Warmer temperatures also extend the growing season. This means that plants need more water to keep growing throughout the season or they will dry out, increasing the risk of failed crops and wildfires. Once the growing season ends, shorter and milder winters fail to kill dormant insects, increasing the risk of large and damaging infestations in subsequent seasons11 . Impacting People: The changes to weather and ecosystems will also affect people more directly (Kumar, S. S. K. H., Himanshu, S. K., & Gupta, K. K. (2012). Effect of global warming on mankind-a review. Int Res J Environ Sci, 1(4), 56-59.). Hardest hit will be those living in low-lying coastal areas and residents of poorer countries who do not have the resources to adapt to changes in temperature extremes and water resources. As tropical temperature zones expand, the reach of some infectious diseases, such as malaria, will change. More intense rains and hurricanes and rising sea levels will lead to more severe flooding and potential loss of property and life. Effects of Global Warming on Water Resources: Both the environment and the human lives are being adversely affected by the phenomenon of global warming. The effects of global warming is myriad and numerous. Several researches were conducted by different organizations and all of them revealed that global warming is increasing at an alarming rate Water Resources impact: Effects of global warming are vast and cover every sphere of one’s life. Both the nature and the living beings are suffering from the effects of global warming. If we do not take note of the alarming rate of growing global warming then our earth might cease to exist someday. The water resources have been heavily affected by the global warming phenomenon. Sea levels have risen, glaciers retreats are taking place often and the most harmful affect is the shrinking of the Arctic Circle.

Global warming, climate change, and environmental pollution present plants with unique combinations of different abiotic and biotic stresses. Although much is known about how plants acclimate to each of these individual stresses, little is known about how they respond to a combination of many of these stress factors occurring together, namely a multifactorial stress combination. Recent studies revealed that increasing the number of different co-occurring multifactorial stress factors causes a severe decline in plant growth and survival, as well as in the microbiome biodiversity that plants depend upon. This effect should serve as a dire warning to our society and prompt us to decisively act to reduce pollutants, fight global warming, and augment the tolerance of crops to multifactorial stress combinations.

(Zandalinas, S. I., Fritschi, F. B., & Mittler, R. (2021). Global warming, climate change, and environmental pollution: recipe for a multifactorial stress combination disaster. Trends in Plant Science, 26(6), 588-599.)

**Global Warming's Impact on Climate Change**

Global warming, the gradual increase in Earth's average temperature primarily due to human activities such as burning fossil fuels and deforestation, has become a defining factor in the phenomenon of climate change. The repercussions of global warming extend far beyond mere temperature increases, encompassing a myriad of environmental, societal, and economic consequences. This essay delves into the intricate relationship between global warming and climate change, highlighting the multifaceted impacts on ecosystems, weather patterns, and human societies.

One of the most conspicuous manifestations of global warming-induced climate change is the alteration of weather patterns and the exacerbation of extreme weather events. Rising temperatures intensify the hydrological cycle, leading to more frequent and severe weather phenomena. Heatwaves become more prolonged and intense, posing significant risks to human health, particularly among vulnerable populations and in urban areas lacking adequate cooling infrastructure. Concurrently, shifts in precipitation patterns result in altered rainfall regimes, with some regions experiencing more frequent droughts while others face increased precipitation and flooding. Such fluctuations destabilize agricultural systems, leading to crop failures, food insecurity, and economic disruptions, especially in regions reliant on rain-fed agriculture.

Moreover, the warming of Earth's atmosphere and oceans triggers the melting of polar ice caps and glaciers, contributing to rising sea levels. This phenomenon poses an existential threat to coastal communities, ecosystems, and infrastructure worldwide. Low-lying coastal regions are particularly susceptible to inundation, coastal erosion, and saltwater intrusion into freshwater sources, jeopardizing livelihoods and exacerbating displacement of populations. Furthermore, the encroachment of seawater into coastal aquifers contaminates drinking water supplies, amplifying the risk of waterborne diseases and exacerbating water scarcity challenges. The cumulative impact of rising sea levels extends beyond immediate coastal areas, with ripple effects on global trade, tourism, and biodiversity as marine habitats are submerged or degraded.

Ecosystems, integral components of Earth's biosphere, face profound disruptions as a consequence of global warming-induced climate change. Shifts in temperature and precipitation regimes alter the distribution and composition of habitats, leading to species range shifts, changes in migration patterns, and loss of biodiversity. Fragile ecosystems such as coral reefs, mangroves, and polar regions are particularly vulnerable to the impacts of global warming, facing threats ranging from coral bleaching and habitat degradation to loss of sea ice and permafrost thawing. These changes reverberate through ecosystems, affecting ecosystem services crucial for human well-being, including pollination, water purification, and climate regulation.

Furthermore, global warming exacerbates existing environmental challenges, including deforestation, habitat fragmentation, and pollution. The synergistic effects of these stressors amplify the vulnerability of ecosystems and species to climate change, hindering their capacity to adapt and survive in a rapidly changing environment. In particular, deforestation and land-use changes contribute to the release of carbon dioxide into the atmosphere, exacerbating the greenhouse effect and perpetuating the cycle of global warming. Additionally, pollution from industrial activities, transportation, and agricultural runoff further degrades ecosystems and compromises their resilience to climate change impacts.

Beyond environmental ramifications, global warming-induced climate change poses formidable challenges to human societies, exacerbating existing inequalities and vulnerabilities. Disproportionate impacts are felt by marginalized communities, including indigenous peoples, smallholder farmers, and residents of low-income urban areas, who have limited resources and adaptive capacity to cope with climate-related shocks. Social unrest, migration, and conflict may ensue as communities grapple with dwindling resources, displacement, and competition over land, water, and other essentials. Furthermore, the economic costs of climate change, including property damage, loss of livelihoods, and increased healthcare expenditures, strain public finances and impede sustainable development efforts.

In conclusion, global warming-induced climate change represents an existential threat with far-reaching implications for the planet's ecosystems, weather patterns, and human societies. Urgent and concerted action is imperative to mitigate greenhouse gas emissions, adapt to the changing climate, and enhance resilience at local, national, and global scales. By addressing the root causes of global warming and fostering equitable and sustainable solutions, humanity can strive towards a more resilient and harmonious coexistence with the natural world.

Ocean Acidification: Global warming not only raises atmospheric temperatures but also influences oceanic conditions. Increased carbon dioxide emissions lead to ocean acidification as the seas absorb more CO2. This acidification disrupts marine ecosystems, particularly coral reefs and shell-forming organisms, compromising their ability to grow and survive. The loss of coral reefs, often referred to as the "rainforests of the sea," diminishes biodiversity and threatens the livelihoods of millions dependent on reef ecosystems for food and income.

Permafrost Thaw: In polar regions and high-altitude areas, the warming climate triggers the thawing of permafrost—permanently frozen ground containing vast amounts of organic matter. As permafrost thaws, previously sequestered carbon and methane are released into the atmosphere, exacerbating global warming and creating a feedback loop. Furthermore, the destabilization of infrastructure built on permafrost, such as roads, buildings, and pipelines, poses additional challenges for communities in these regions.

Impact on Agriculture: Global warming alters agricultural productivity and food security worldwide. Changes in temperature and precipitation patterns affect crop yields, pest and disease prevalence, and water availability, leading to reduced agricultural output and increased food prices. Smallholder farmers, particularly in developing countries, bear the brunt of these impacts, facing challenges in adapting to changing climatic conditions and maintaining their livelihoods. Furthermore, climate change-induced disruptions in food production exacerbate hunger and malnutrition, perpetuating cycles of poverty and vulnerability.

Loss of Glacial Water Resources: Glaciers, vital sources of freshwater for millions of people worldwide, are rapidly receding due to global warming. The loss of glaciers jeopardizes water availability for drinking, irrigation, and hydropower generation, particularly in regions dependent on glacial meltwater during dry seasons. Communities relying on glacier-fed rivers face heightened water insecurity, exacerbating tensions over water allocation and management. Additionally, glacier retreat alters river flow patterns, impacting downstream ecosystems and biodiversity.

Threat to Biodiversity Hotspots: Global warming poses a significant threat to biodiversity hotspots—regions with exceptionally high levels of species richness and endemism. As temperatures rise and habitats shift, species struggle to adapt or migrate to suitable areas, leading to population declines and increased extinction risks. Fragmentation of habitats further compounds the challenges faced by species, limiting their ability to disperse and find suitable habitats. The loss of biodiversity not only undermines ecosystem resilience but also diminishes the services provided by ecosystems, including carbon sequestration, pollination, and soil fertility.

Risk of Tipping Points: Global warming increases the likelihood of triggering irreversible tipping points in Earth's systems, leading to abrupt and potentially catastrophic changes. Examples include the collapse of major ice sheets, disruption of ocean circulation patterns, and release of methane hydrates from the ocean floor. These tipping points have the potential to amplify the impacts of global warming, accelerate climate change, and exceed the adaptive capacity of ecosystems and societies. Mitigating the risk of tipping points requires urgent action to reduce greenhouse gas emissions and strengthen resilience to climate-related hazards.

In summary, global warming-induced climate change manifests in diverse and interconnected ways, posing profound challenges for ecosystems, societies, and economies worldwide. Addressing these challenges requires a holistic approach that integrates mitigation, adaptation, and sustainable development strategies. By acknowledging the complex interactions between human activities and the natural environment, we can strive towards a more equitable, resilient, and sustainable future for all.

(Cerri, C. E. P., Sparovek, G., Bernoux, M., Easterling, W. E., Melillo, J. M., & Cerri, C. C. (2007). Tropical agriculture and global warming: impacts and mitigation options. Scientia Agricola, 64, 83-99.)

**Impact of climate change on the tropical agriculture**

Global climate changes caused by increased greenhouse gas emissions to the atmosphere from an thropogenic activities have direct influence on natural and agrosystem functioning (Lal, 2002). Modifications in hydrologic regimes and atmosphere temperature due to anthropogenic greenhouse effect provoke variations in plant productivity and therefore, affect food production (IPCC, 2003).

Crop simulation models, driven by future climate scenarios from global circulation models, suggest that the reduction in agricultural production would be more severe in tropical regions (IPCC, 2001), where there is still a shortage of food production.

No clear picture has emerged on the regional consequences of climate change for agricultural production. However, uncertainties are beginning to narrow on some general research findings. The Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC), summarized by Easterling & Apps (2005), reported that models simulate the capacity of temperate crops to absorb 2-3 degrees C of warming before showing signs of stress. Crops grown in the tropics, wheat especially, exhibit immediate yield decline with even the slightest warming ([Figure 2](https://www.scielo.br/j/sa/a/rqTCsnspnQfkpWHBCYwwW7q/)) because they are currently grown under conditions close to maximum temperature toleranceseven a little warming sends them over the edge. Developing countries everywhere will strain to maintain food security while preserving ecosystem services as they meet the challenges of climate change.

Brazil, located almost entirely in the tropical zone, is not an exception to this rule, and therefore, is susceptible to reductions in agricultural and cattle ranching production. Moreover, agriculture comprises the largest single sector of the Brazilian economy, representing 29% of the Gross Domestic Product (GDP) in 2002, and about 47.5% of the Brazilian exports in 2003. Therefore, understanding the possible impacts of climate change on the Brazilian agriculture is a key point for governmental decision-makers, in order to avoid jeopardizing domestic food production and agricultural exports.

Research about the impacts of climate change on Brazilian agriculture is scanty and has focused mainly only on grain production (Siqueira et al., 1994; 2001). Simulations of grain production are usually done by coupling a crop growth model with a climate change scenario and projected increases in CO2 from a future emission scenario, using historical climate data and current CO2levels as a base scenario.

Siqueira et al. (1994; 2001) presented results on wheat (*Triticum vulgare* Vill), maize (*Zea mays* L.) and soybean (*Glycine max*L. Merr) production simulations with the crop growth model CERES and SOYGRO for 13 Brazilian situations under climate change scenarios generated by GISS (Goddard Institute for Space Studies), GFDL (Geophysical Fluid Dynamic Laboratory) and UKMO (United Kingdom Meteorological Office) GCMs run with 330 and 555 ppm CO2.

Siqueira et al. (2001) reported that simulations show an increase in the mean air temperature between 3 to 5ºC and an increase of about 11% in the mean precipitation for the Center-South region throughout the year 2050. This scenario would cause a reduction of 30 and 16% of the wheat and corn productions, respectively; and an increase of about 21% in the soybean production. These figures correspond to a reduction of 1 million tonnes of wheat and 2.8 million tonnes of corn and an increase of 3.5 million tonnes of soybean. The major problems resultant from additional rainfall are related to higher probability of disease incidences, greater difficulties in cultivation management and higher risks of soil water erosion.

Sivakumar & Das (2005) pointed out that periodic occurrences of severe El Niño  associated droughts in northeastern Brazil have resulted in occasional famines. Under doubled-CO2 scenarios, yields are projected to fall by 17 to 53% depending on whether or not direct effects of CO2 are considered.

The effects of the climate change scenarios in the agroclimatic zoning of arabic coffee (*Coffea arabica*L.) is important in the main plantation areas in Brazil (Silva et al., 2006). The simulations presented by Assad et al. (2004) indicate a reduction of suitable areas greater than 95% in the states of Goiás, Minas Gerais and São Paulo, and about 75% for Paraná when the temperature increases in 5.8ºC. In terms of annual crop production, the effects of the high temperatures are negative.

**Plant pests**

Plant pests, which include insects, pathogens and weeds, continue to be major constraints to food and agricultural production in both developed and developing countries (Burdon et al., 2006). Crop losses significantly reduce the amount of food available for human and animal consumption, thus contributing directly to food insecurity and poverty (Epstein & Mills, 2005). They also negatively affect internal and external marketing and trade in agricultural products, reduce farmers' income, and block poverty alleviation (IPCC, 2001).

Global drivers of plant pest problems include intensification of cropping which provides greater host availability for pests, international trade and food aid that increases the movements of plants and often their accompanying pests, migration and tourism that increase movement of people who carry plant materials, and civil conflict and war, that both increase movement of refugees and military personnel and disrupt phytosanitary control systems at borders (FAO, 2005).

Climate change as a driver will have different effects on the various types of pests (Garrett et al., 2006; Ghini & Morandi, 2006). Based on studies of individual species, climate change may affect: pest developmental rates and numbers of pest generations per year; pest mortality due to cold and freezing during winter months; or host plant susceptibility to pests (Burdon et al., 2006). When two or more species contribute to a pest problem, as with vectored pathogens or pathogens which cause more severe symptoms in the presence of simultaneous insect damage, the effects of climate change could be expressed through any of these species (Ghini, 2005; Garrett et al., 2006). Overall temperature increases may influence crop pathogen interactions by speeding up pathogen growth rates, which increases reproductive generations per crop cycle (Ghini & Morandi, 2006), by decreasing pathogen mortality due to cold winter temperatures, and by effects on the crop itself that leave the crop more vulnerable (FAO, 2005).

As if the inter-relationships between plants, pest organisms, and the existing environment weren't staggeringly complex, the onus of potential global climate change bodes yet further complications of the fragile equation (Ghini, 2005). With a specific focus on major classes of crop pests, Pritchard & Amthor (2005) suggest that: i) warming may favor most weeds in comparison to crops; ii) rising CO2 also is likely to enhance weed growth relative to crops; iii) being highly adaptable, many weed species can be expected to rapidly and more effectively adapt to increasing stresses such as rising atmospheric ozone and soil salinization; iv) warming trends most likely will also increase abundance, growth rate, and geographic range of many key crop-attacking insect pests; v) warming may, depending on the shifting of precipitation patterns, stimulate microbial pathogens; vi) crop tissue chemistry, including nitrogen and water content as well as inducible defense mechanisms, is likely to evolve as environmental change occurs; vii) on the plus side, rising CO2 may stimulate rhizobia and mycorrhizae and benefit both crop plants and soil dwelling symbionts; and viii) warming (soil) may be beneficial in some regions, but harmful in those regions where optimal soil temperatures already exist.

Control of plant pests still involves substantial use of pesticides, which protect crops and boost productivity but can have severe side effects on human health and the environment (Epstein & Mills, 2005). The risks for developing countries  where farmers cannot afford less toxic compounds, proper application equipment and appropriate personal protection  are particularly great (FAO, 2005). Genetically modified crops offer a solution to the control of weeds and some pests  and their use has increased as a result (Garrett et al., 2006).

**Examples of management practices for greenhouse gas emission reduction and soil carbon sequestration**

**Conventional versus no-tillage system**

No-tillage is presumed to be the oldest system of soil management. In some parts of the tropics, No-tillage is still practiced as part of slash-and-burn agriculture. After clearing an area of forest, by controlled burning, seed is placed directly into the soil. However, as mankind developed more systematic agricultural systems, cultivation of the soil became an accepted practice as a means of preparing a more suitable environment for plant growth. Paintings in ancient Egyptian tombs portray farmers tilling their fields using a swing-plough and oxen, prior to planting. Indeed, tillage as symbolized by the mouldboard plough became almost synonymous with agriculture (Dick & Durkalski, 1997). No-tillage can be defined as a crop production system where soil is left undisturbed from harvest to planting except for fertilizer application.

Conversion of native vegetation to cultivated cropland under conventional tillage system has resulted in a significant decline in soil organic matter content (Paustian et al., 2000; Lal, 2002). Farming methods that use mechanical tillage, such as the mouldboard plough for seedbed preparation or discing for weed control, can promote soil C loss by several mechanisms: they disrupt soil aggregates, which protect soil organic matter from decomposition (Karlen & Cambardella, 1996; Six et al., 1999; Soares et al., 2005), they stimulate short-term microbial activity through enhanced aeration, resulting in increased levels of CO2 and other gases released to the atmosphere (Bayer et al., 2000a; 2000b; Kladivko, 2001), and they mix fresh residues into the soil where conditions for decomposition are often more favourable than on the surface (Karlen & Cambardella 1996; Plataforma Plantio Direto, 2006). Furthermore, tillage can leave soils more prone to erosion, resulting in further loss of soil C (Bertol et al., 2005; Lal, 2006).

No-tillage practices, however cause less soil disturbance, often resulting in significant accumulation of soil C (Sá et al., 2001; Schuman et al., 2002) and consequent reduction of gas emissions, especially CO2, to the atmosphere (Lal, 1998; Paustian et al., 2000) compared to conventional tillage. There is considerable evidence that the main effect is in the topsoil layers with little overall effect on C storage in deeper layers (Six et al., 2002).

Globally, at present, approximately 63 million ha are under no-tillage systems with USA having the largest area (Lal, 2006). In Brazil the no-tillage system started in the south region (Paraná State) in 1972 as an alternative to the misuse of land causing erosion (Denardin & Kochhann, 1993). The underlying land management principles that led to the development of no-tillage systems in Brazil were, prevention surface sealing caused by rainfall impact, achievement and maintenance of an open soil structure and reduction of the volume and velocity of surface runoff. Consequently, the no-tillage strategy was based on two essential farm practices: (i) not tilling and (ii) keeping soil covered at all times. This alternative strategy quickly expanded to different states and the planted area under no-tillage has since then increased exponentially.

In the early 90's the area covered by the system was 1 million ha increasing 10 times by 1997. Now, the approximately 20 million ha covered by no-tillage practice (Febrapdp, 2006) make Brazil the second largest adopter in the world. This expansion is taking place not only as result of the conversion from conventional tillage in the southern region (72%) but also after clearing natural savannah in centre-west area (28%). More recently, due to the high profits, ranchers in the Amazon region are converting old pastures to soybean/millet under no-tillage.

Changes in soil C stocks under no-tillage have been estimated in earlier studies for temperate and tropical regions. Cambardella & Elliott (1992) showed an increase of 6.7 t C ha-1 in the top 20 cm in a wheat-fall rotation system after 20 years of no-tillage in comparison to conventional tillage. Reicosky et al. (1995) reviewed various publications and found that organic matter increased under conservation management systems with rates ranging from 0 to 1.15 t C ha-1 yr-1, with highest accumulation rates generally occurring in temperate conditions. Lal et al. (1998) calculated a C sequestration rate of 0.1 to 0.5 t C ha-1 yr-1 in temperate regions. For the tropical west of Nigeria, Lal (1997) observed a 1.33 t C ha-1 increment during 8 years under no-tillage as compared to the conventional tillage of maize, which represents an accumulation rate of 0.17 t C ha-1 yr-1.

In the tropics, specifically in Brazil, the rate of C accumulation has been estimated in the two main regions under no-tillage systems (south and centre-west regions). In the southern region Sá (2001) and Sá et al. (2001) estimated a greater sequestration rates of 0.8 t C ha-1 yr-1 in the 0-20 cm layer and 1.0 t C ha-1 yr-1 in the 0-40 cm soil depth after 22 years under no-tillage compared to the same period under conventional practice. The authors mentioned that the accumulated C was generally greater in the coarse (> 20 µm) than in the fine (< 20 µm) particle-size-fraction indicating that most of this additional C is weakly stable.

Bayer et al. (2000a; 2000b) found a C accumulation rate of 1.6 t ha-1 yr-1 for a 9 year no-tillage system compared with 0.10 t ha-1 yr-1 for the conventional system in the first 30 cm layer of an Acrisol in the southern part of Brazil. Corazza et al. (1999) reported an additional accumulation of approximately 0.75 t C ha-1 yr-1 in the 0-40 cm soil layer due to no-tillage in the savannah region located in the central-west . Estimates by Amado et al. (1998;1999) indicated an accumulation rate of 2.2 t ha-1 yr-1 of soil organic C in the first 10 cm layer. Other studies considering no-till system carried out in the centre-west part of Brazil (Lima et al., 1994; Castro-Filho et al., 1998; Riezebos & Loerts, 1998; Vasconcellos et al., 1998; Peixoto et al., 1999; Spagnollo et al., 1999; Resck et al., 2000) reported soil C sequestration rates due to no-tillage varying from 0 up to 1.2 t C ha-1 yr-1 for the 0-10 cm layer.

**Burning versus non-burning harvesting sugar cane system**

The sugar cane crop offers one of the most cost-effective renewable energy sources that are readily available in developing countries (Macedo, 1998). It is a highly efficient converter of solar energy and, in fact, has the highest energy-to-volume ratio of all energy crops (Johnson, 2000). Sugar cane is a perennial crop that is harvested on an annual cycle. There may be up to six cycles before re-planting. There is generally only a short fallow between ploughing out the old cane and re-planting. On the majority of farms in Brazil sugar cane is grown as a monoculture (Macedo, 1997; Simões et al., 2005). It is a highly flexible resource, offering alternatives for production of food, feed, fibre and energy. Such flexibility is valuable in the developing world where fluctuations in commodity prices and weather conditions can cause severe economic hardships.

For biomass energy production, sugar cane is an excellent feedstock in terms of efficiency and flexibility, providing gaseous, liquid and solid fuels (Ripoli et al., 2000). It offers the potential for climate change mitigation through substitution of fossil fuels without the need for excessive subsidies or expensive infrastructure development (Oliveira et al., 2005).

The Brazilian ethanol programme remains the world's largest CO2 mitigation programme (Johnson, 2000; Oliveira et al., 2005). At present in Brazil, sugar cane is cultivated on about 5 million ha, with an average annual production of approximately 300 million tonnes (FNP, 2006). In 1999/00 about 19 million tonnes of sugar and 12 million m3 of alcohol were produced (CENBIO, 2002).

There are two procedures adopted for sugar cane harvesting. Traditionally, sugar cane was burnt in the field a few days before harvesting in order to facilitate manual cutting by removing leaves and insects (Thorburn et al., 2001). However, since May 2000 this common practice has been progressively prohibited by law in some areas in Brazil. In addition to CO2 emission, other pollutant gases are emitted during the burning period causing respiratory problems and ash fall over urban areas (Andreae & Merlet, 2001). Even though the law will not be fully implemented before 2030, the adoption of mechanical harvesting has increased exponentially in Brazil during the last decade. In 1997 about 20% of the Brazilian sugar cane area was harvested by machines (Silva, 1997) and it is estimated that about 80% of the planted area in the most productive sugar cane region in Brazil will use mechanical harvesting in the next 20 years (CENBIO 2002).

The current mechanical approach is only adapted for slopes of less than 12% (Luca, 2002) and it seems likely that when the burning ban is fully implemented steeply sloping land will go out of sugar cane production unless new harvesting methods are developed (Simões et al., 2005). By the return of crop residues to the soil surface the mechanical approach has indirectly favoured soil organic matter accumulation (Thorburn et al., 2001; Luca, 2002) and gas emission reduction when compared to the burning system (Andreae & Merlet, 2001).

The net contribution of the Brazilian sugar cane industry to the evolution of atmospheric CO2 is a combination of three activities, two industrial and one agricultural. The first activity is the substitution of gasoline as a fuel by alcohol. Since the early 1930's the Brazilian government has given incentives for alcohol production from sugar cane to be added to gasoline in the transportation sector (Sociedade Nacional de Agricultura, 2000). Due to the oil crises in 1973-74, Brazilian authorities created new incentives through the Brazilian alcohol program (Proalcool) to increase the production of alcohol to 10.7 billion litres per year (Coelho et al., 2000). During 1975 to 2000, 156 million m3 of hydrated alcohol and 71 million m3 of anhydrous alcohol were produced. Considering that 1 m3 of gasoline can be substituted by 1.04 m3 anhydrous alcohol and 0.8 m3 hydrated alcohol and that gasoline contains on average 86.5 % C (American Petroleum Institute, 1988) we calculate that during the 1975-2000 period, 172 Mt C were offset and consequently not emitted to the atmosphere, which gives an average annual offset of 6.8 Mt C. However, the alcohol production and consumption are increasing every year in Brazil. If data just for the last 10 years were used, the offset would be about 10 Mt C yr-1.

The second associated mitigation factor in the sugar cane system is related to the use of plant residues as a fuel. At the mill, the cane stalks are shredded and crushed to extract the cane juice while the fibrous outer residue, known as bagasse, is burnt to provide steam and electricity for the mill (Luca, 2002). For instance, in 1998 approximately 45 Mt dry matter of sugar cane residues were produced in Brazil (Brasil, 1999). Assuming that 2.35 t of residues substitute for 1 t of fossil fuel (Macedo, 1997) we estimate that 8 Mt C were offset in 1998 due to use of sugar cane residues at the mill instead of fuel. This renewable energy resource, found mainly in developing countries, has obvious appeal for international efforts to reduce carbon dioxide emissions. Moreover, the organic wastewater stream from alcohol production, known as vinasse, can be used as fertilizer or can be converted to methane gas through anaerobic digestion. The transportation fleets used in sugar factories and ethanol distilleries in Brazil have in some cases been powered by methane gas (Johnson, 2000). The production of alcohol has been viewed as a valuable means of saving foreign exchange in developing countries while at the same time providing local and global environmental benefits (Oliveira et al., 2005). In addition to climate mitigation and reduction of local pollutants, it can serve as an octane enhancer that might speed the phasing-out of leaded gasoline. The economic and environmental attractiveness of sugar cane as a renewable energy resource and the variety of options for increasing use of cane by-products and co-products could one day lead to sugar becoming the by-product rather than the main product.

Finally, the third activity associated with CO2 mitigation in the sugar cane system is the conversion harvesting without prior burning. At present there are 5 Mha of sugar cane grown in Brazil (FNP, 2006) of which approximately 20% (1.5 Mha) is harvested without burning (Silva, 1997; Oliveira et al., 2005). In the absence of burning, sugar cane residues are returned to the soil surface with litter and this factor is significant because it contrasts with the alternative system where cane is burnt before harvest removing dead and green leaves, so there is very little C returned to the soil from the above ground vegetation. For instance, Blair et al. (1998) found increases in the labile C fraction in green trash treatments as compared to the trash burnt treatments in the surface soils of two green trash management trials in Australia. In Southern Brazil, Feller (2001) reported that an average of 0.32 t C ha-1 yr-1 was accumulated in 12 years in the first 20 cm depth of an Oxisol due to the elimination of burning. Other estimates exist, but for shorter periods of no-burning. For instance, Luca (2002) reported increases ranging from 2 to 3.1 and 4.8 to 7.8 t C ha-1 respectively for the top 5 cm and 40 cm depth during the first 4 years following no-burning. The corresponding annual increase ranges from 0.5 to 0.78 t C ha-1 yr-1 for the 0-5 cm layer and 1.2 to 1.9 t C ha-1 yr-1 for the 0-40 cm layer. However, sugar cane is typically replanted each 6-7 years and tillage practices are then commonly used. This procedure would probably reduce the high rates presented by Luca (2002) if the study had been for a longer period. In our estimate of C sequestration we have used the value found by Feller (2001) because it represents the longest period of harvest without burning in Brazil and incorporates cane replanting. Thus, considering the area under this management system and the mean annual C accumulation rate, a total of 0.48 Mt C yr-1 is sequestered in Brazil.

When sugar cane is burnt other greenhouse gases like CH4 and N2O are emitted to the atmosphere. Macedo (1998) shows that 6.5 kg CH4 ha-1 are released from the burning of sugar cane. Considering the total area with sugar cane under no burning harvesting system (1.5 Mha) and that the methane has the global warming potential of 21, we have calculated that 0.2 Mt CO2-equivalent (0.05 Mt C) that are not emitted annually to the atmosphere due to the adoption of no burning. The same calculation is required for N2O emission; however, currently there are no adequate measurements of this gas for sugar cane.

In summary, when sugar cane is harvested mechanically without burning in Brazil, 0.48 Mt C yr-1 is sequestered in soil and methane emission equivalent to 0.05 Mt C yr-1 is avoided. This total of 0.53 Mt C yr-1 is the contribution of the agricultural sector. Moreover, the industrial sector contributes not only the 10 Mt C yr-1 offset due to substitution of fossil fuel by alcohol for transportation but also the 8 Mt C yr-1 by substituting fossil fuel for power generation at the mill. Combining the agricultural and the industrial sectors, sugar cane produced without burning gives a total of 18.5 Mt C yr-1 removed from the atmosphere.

**Sequestration opportunities**

The cultivated area under no-tillage in Brazil is increasing rapidly at an average of 2.4 million ha per year over the last five years. Assuming the same growth pattern, projections show that in less than ten years the cultivated area under no-tillage will be doubled. Consequently, estimated values for soil C accumulation (10 Mt C yr-1) presented may be doubled in the next 10 years.

The no burning harvest system adopted on 20% of the crop in Brazil contributing through soil C sequestration and C offset at a rate of 18.5 Mt C yr-1. This rate is going to increase substantially as the no-burning system is expected to reach 50% of the crop in the next decade (Macedo, 1998).

Estimated annual fluxes for Brazilian agriculture indicate a net emission of 46.4 Mt CO2 (or 12.65 Mt C) to the atmosphere for the period 1975-1995. However, the main changes in agricultural management discussed in this report contribute together to CO2 mitigation with a total of 10.53 Mt C yr-1. Of this total 10 Mt C yr-1 relates to adoption of no-tillage and 0.53 Mt C yr-1 relates to introduction of sugar cane harvesting without burning. The implementation of these two practices is almost sufficient to compensate for the net soil emissions of 12.65 Mt C yr-1.

Apparently, no-tillage is more effective in sequestering C than harvesting cane without burning. However, we should emphasize that the area under no-tillage is about 10 times greater than the area under sugar cane. The C sequestration rate per unit area under no-tillage is slightly more than the rate for no burning. If the CO2-equivalent of N2O emitted during burning of sugar cane is subtracted, these rates would probably be similar. In addition to the CO2 mitigation benefit due to no-tillage sugar cane has extra benefits derived from the substitution of fossil fuel by alcohol and bagasse.

In addition to the CO2 mitigation related to the main management practices here discussed, the adoption of good management strategies has the potential to raise soil C levels and consequently improve soil structure. This results in increased infiltration, better soil water relations, reduced surface sealing and erosion which should lead to increased crop yields. The improvement and maintenance of soil C and soil structure is necessary for sustainable agricultural systems and conservation of the soil resource.

**Impact of climate change on soil organic matter status in cattle pasture in Western Brazilian Amazon**

Most studies concerning the impact of climate change on food security deal with grain production only. But beef production, with 175 million cattle in 2001, represents a large component of Brazilian agriculture. About 30% of the total is in the Amazon region where pastures are typically extensively managed and are on low fertility soils. The sustainability of these fragile ranching systems can be evaluated through the soil organic matter (SOM) status. A changing climate can induce losses of soil organic matter, upsetting the input-output nutrient balance and provoke losses in plant grass productivity, and subsequently sustainability of the overall system.

The main objective of this section was to estimate changes induced by potential climatic change on soil organic matter stocks in extensive pastures of the Brazilian Amazon region, using a modeling approach. In order to do so, we have applied the Century Ecosystem Model (Century 4.0) using Tyndall Center climatic predictions to simulate soil carbon stocks and fluxes in a chronosequence of forest to pasture located within the Nova Vida Ranch in the Rondônia State, in the western part of the Brazilian Amazon.

**Conclusion**

Global warming poses a significant threat to Earth and all life on it, including human life, due to its wide-ranging impacts on the environment, economy, and society. The accumulation of greenhouse gases, primarily carbon dioxide, in the Earth's atmosphere has led to an increase in global temperatures, causing changes in weather patterns, rising sea levels, loss of biodiversity, and extreme weather events.

One of the most immediate and visible consequences of global warming is the melting of polar ice caps and glaciers, leading to rising sea levels. This not only threatens coastal communities and ecosystems but also exacerbates the frequency and intensity of flooding events, displacing millions of people and causing immense economic losses.

Furthermore, changes in weather patterns and the frequency of extreme weather events, such as hurricanes, droughts, heatwaves, and wildfires, are becoming more pronounced and disruptive. These events not only result in loss of life and property but also strain infrastructure, healthcare systems, and economies.

The impact of global warming extends beyond the natural world to human health, agriculture, and food security. Increasing temperatures and changing precipitation patterns affect crop yields, leading to food shortages, higher prices, and increased malnutrition. Additionally, the spread of infectious diseases, such as malaria and dengue fever, is facilitated by warmer temperatures and shifting habitats for disease vectors.

Moreover, global warming exacerbates existing social inequalities, disproportionately affecting marginalized communities who often have fewer resources to adapt and mitigate its effects. This can lead to increased social unrest, migration, and conflict over dwindling resources, exacerbating geopolitical tensions and threatening global stability.

In conclusion, global warming is a grave threat to Earth and human life, necessitating urgent and concerted action on a global scale to mitigate its impacts, transition to renewable energy sources, adapt to the changes already underway, and build resilience in vulnerable communities. Failure to address this challenge effectively will result in irreversible damage to ecosystems, economies, and societies, with profound consequences for current and future generations.

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