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Exploring the Consequences of Climate Change on Agriculture: A Literature Review

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Abstract
Climate change poses a significant challenge to global agriculture, influencing food production, water availability, and ecosystem stability. Rising temperatures, altered precipitation patterns, and increasing greenhouse gas concentrations are disrupting traditional agricultural systems, particularly in developing countries where food security is already at risk. Projections suggest a global temperature rise of 1.4°C to 5.8°C by 2100, which could reduce crop yields, increase drought frequency, and escalate pest and disease outbreaks. Agricultural productivity is projected to decline by 3% to 16% globally by 2080, with some developing nations experiencing up to a 40% reduction in yields. Adaptation strategies, including climate-resilient crop varieties, precision agriculture, and water conservation measures, are critical to mitigating these impacts. This review highlights the urgent need for coordinated global action to address climate change's impact on agriculture. Sustainable farming practices, investments in climate-smart agriculture, and policy frameworks supporting adaptation will be essential in ensuring long-term food security and environmental stability.
Keywords: *Climate Change, Agricultural Productivity, Food Security, Water Scarcity, Adaptation Strategies*

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I. Introduction

Climate change has a significant impact on local weather conditions, which in turn affects agriculture both positively and negatively. Over the past century, the rate of climate change has increased significantly, posing a serious threat to global food security, water resources, and human health (Magadza, 2000; Arora, 2019). Addressing this issue on a priority basis is critical, as scientists warn that the earth may experience a temperature increase of 2.5 to 4.5ºC by the end of the 21st century due to the continuous rise in greenhouse gases (Bernstein et al., 2007; Tripathi et al., 2016). With higher temperatures and elevated CO_2 levels, scientists have developed new strategies to cope with the less predictable challenges posed by climate change (Rosenzweig et al., 2014).

When it comes to vulnerability to climate change, six out of the top 10 most susceptible countries are located in the Asia-Pacific region. Bangladesh is at the top of this list, followed by India, Nepal, the Philippines, Afghanistan, and Myanmar. In Bangladesh, it is estimated that roughly 20% of the population could be displaced due to the loss of agricultural land caused by a 1.5m rise in sea level. In the case of the Maldives, a sea-level increase of 2m would submerge about half of the country's land area.

Climate change is expected to have a direct impact on global food production. An increase in mean seasonal temperatures may shorten the growth duration of numerous crops, thereby reducing their final yield. In regions where temperatures are already approaching the physiological limits for crop growth, further warming will have an immediate adverse effect on yields (IPCC, 2007). The agricultural sector worldwide is anticipated to experience a significant decline within this century due to global warming. Projections indicate that overall global agricultural productivity will decrease by approximately 3% to 16% by 2080. Developing nations, many of which already experience average temperatures near or exceeding crop tolerance thresholds, are expected to face an average reduction in agricultural productivity of 10% to 25% by the 2080s. In contrast, wealthier nations, which generally have lower average temperatures, are projected to experience more moderate impacts, with changes in productivity ranging from an 8% increase to a 6% decline. Some developing countries may experience even more severe declines; for instance, India could face a reduction in agricultural productivity of 30% to 40%.

Climate change is expected to have a direct impact on food production worldwide. An increase in average seasonal temperatures can shorten the growing period for many crops, leading to lower final yields. In regions where temperatures are already near the maximum that crops can tolerate, further warming will have an even more immediate impact on yields (IPCC, 2007).

Global agriculture is facing a significant decline this century due to global warming. By 2080, overall agricultural productivity is projected to decrease by 3% to 16% worldwide. Developing countries, many of which already experience temperatures close to or above what crops can handle, are expected to see a decline in agricultural productivity ranging from 10% to 25% by the 2080s. In contrast, wealthier countries, which generally have lower average temperatures, may face a much smaller impact, with estimates ranging from an 8% increase to a 6% decrease in productivity. Individual developing countries could see even steeper declines; for instance, India might experience a reduction in productivity of 30% to 40%.

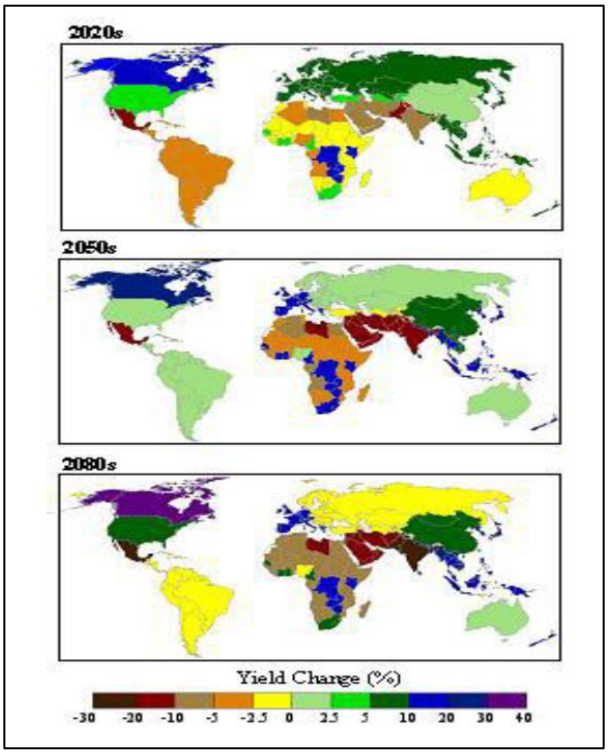

Fig. 1 Results of Hadley Climate model showing possible crop yields in the future (2020s,2050s and 2080s).

The figure (Figure-1) illustrates the results from the Hadley climate model for the years 2020, 2050, and 2080. The maps indicate that rising temperatures in many regions of Africa are expected to decrease food production. In Australia, reduced rainfall is projected to lower crop yields, though in some cases, this drop could be mitigated through irrigation. In North America, increased rainfall combined with a moderate rise in temperatures might actually boost food production.

Climate change is likely to disproportionately impact poorer nations. When interpreting the maps, it's important to consider that the outcomes depend on factors like climate, the effects of CO2 levels on crop growth, and changes in socioeconomic conditions. For instance, developed countries can often use irrigation to offset lower rainfall, but such technological solutions may not be feasible in less developed nations.

Table -1 Predicted effects of climate change on agriculture over the next 50 years

Climatic Element	Expected Change by 2050's	Confidence in Prediction	Effects on Agriculture
CO_2	Increase from 360 ppm to 450 - 600 ppm (2005 levels now at 379 ppm)	*Very high*	Good for crops: increased photosynthesis; reduced water use
Sea level rise	Rise by 10 -15 cm Increased in south and offset in north by natural subsistence/rebound	*Very high*	Loss of land, coastal erosion, flooding, salinisation of groundwater
Temperature	Rise by 1-2°C. Winters warming more than summers. Increased frequency of heat waves	*High*	Faster, shorter, earlier growing seasons, range moving north and to higher altitudes, heat stress risk, increased evapotranspiration
Precipitation	Seasonal changes by ± 10%	*Low*	Impacts on drought risk' soil workability, water logging irrigation supply, transpiration
Storminess	Increased wind speeds, especially in north. More intense rainfall events.	*Very low*	Lodging, soil erosion, reduced infiltration of rainfall
Variability	Increases across most climatic variables. Predictions uncertain	*Very low*	Changing risk of damaging events (heat waves, frost, droughts floods) which effect crops and timing of farm operations

Source: Climate change and Agriculture, MAFF (2000) Adopted from Mahato (2004).

As presented in the table (Table-1) the predicted impacts of climate change on agriculture over the next 50 years, focusing on key climatic elements. CO_2 Levels Expected to rise from 360 ppm to 450-600 ppm by the 2050s, with a very high confidence. This increase could enhance crop growth through better photosynthesis and more efficient water use. Sea Level Rise is predicted rise 10-15 cm, with a very high-level prediction. This may lead to the loss of agricultural land, coastal erosion, flooding, and groundwater salinization. Temperature expected to increase by 1-2°C, with a higher rise in winter and more frequent heatwaves. The prediction confidence is high in this regard. This change could lead to shorter growing seasons, shifts in suitable growing regions, and higher water needs due to increased evapotranspiration. Seasonal fluctuations in precipitation up to ±10% are anticipated, with low confidence. These changes could affect drought risk, soil conditions, irrigation, and water availability. An expected increase in wind speeds (storminess) and more intense rainfall is predicted with very low confidence. This could result in crop damage, soil erosion, and reduced water absorption by the soil. An increase in climate variability is expected, though predictions are uncertain, with very low confidence. This could lead to more extreme weather events like heat waves, frosts, droughts, and floods, impacting crop cycles and farm operations.

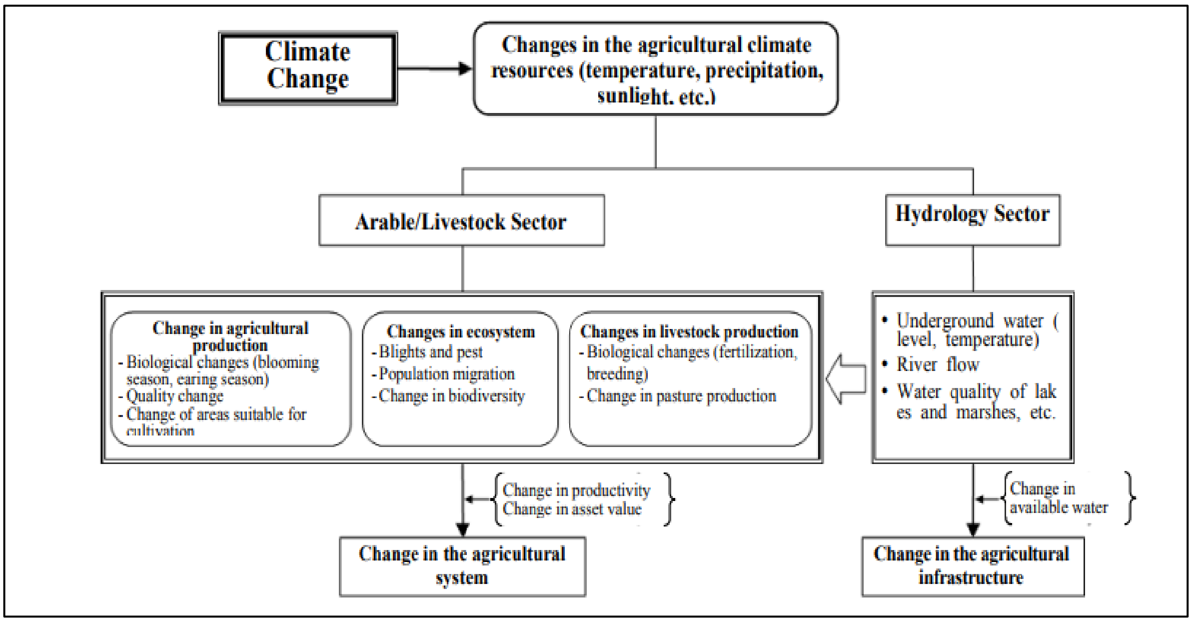

Fig-2 Impact of Climate Change on Agriculture. *Source: Kim, Chang-Gil and et al. (2009), p.36.*

The diagram highlights how climate change impacts agriculture by affecting both the Arable/Livestock Sector and the Hydrology Sector. Climate change alters key agricultural climate resources, such as temperature, precipitation, and sunlight, which directly influence agricultural production. In the Arable/Livestock Sector, these changes can lead to shifts in the biological processes of crops, like changes in blooming and caring seasons, variations in crop quality, and shifts in the regions suitable for cultivation. The ecosystem is also affected, with potential increases in pests, changes in animal migration patterns, and impacts on biodiversity. Livestock production may face challenges due to alterations in fertilization, breeding, and pasture conditions. These factors collectively influence agricultural productivity and asset value, causing significant shifts in the overall agricultural system. Simultaneously, climate change impacts the Hydrology Sector by altering groundwater levels and temperatures, river flows, and the quality of water in lakes and marshes. These water-related changes affect the availability of water necessary for agriculture, influencing the agricultural infrastructure needed to support crops and livestock. Overall, the diagram illustrates how interconnected and multifaceted the consequences of climate change are on agriculture, highlighting the need for adaptive strategies to sustain agricultural productivity.

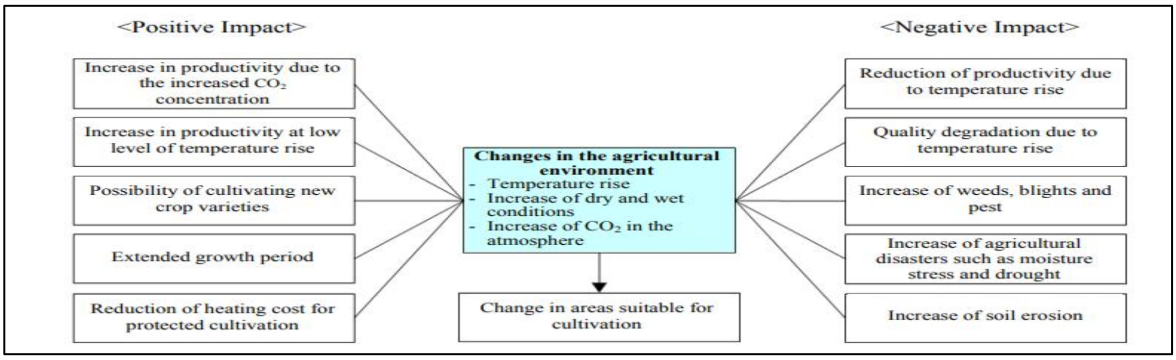

Fig -3 Positive and Negative impact of Climate Change in the Agricultural Environment [*Source: Kim, Chang-Gil and et al. (2009), p.38.*]

Global warming has both positive and negative impacts on agriculture, making its effects complex and multifaceted. On the positive side, higher levels of carbon dioxide in the atmosphere can enhance crop productivity through the "fertilization effect," and warmer temperatures can expand the areas suitable for tropical and subtropical crops. Additionally, longer growing seasons provide opportunities for double cropping, reducing winter crop damage from extreme cold, and lowering heating costs in greenhouses and other protected cultivation facilities. However, the negative consequences of global warming are significant. Rising temperatures can shorten the growing season, leading to reduced crop yields and quality. Fruit production may suffer, with lower sugar content, poor coloration, and decreased storage stability. Warmer climates are likely to encourage the spread of pests, diseases, and invasive weeds, while accelerated decomposition of organic matter can diminish soil fertility. Increased rainfall also raises the risk of soil erosion, further threatening agricultural stability. As climate change alters regional climates, the suitability of certain areas for specific crops will shift, with cultivation zones moving northward. This change can be both a crisis for some regions losing their agricultural suitability and an opportunity for others gaining new growing potential. The impact of climate change on agriculture, therefore, has both positive and negative dimensions, with opportunities for growth alongside significant risks. To ensure sustainable agricultural development, it is essential to create adaptation strategies that maximize benefits and minimize challenges.

Impact on Water Availability: Climate change is a significant contributor to increasing pressure on the hydrological cycle, alongside other factors such as pollution, population growth, and land use changes (Aerts & Droogers, 2004). According to a report by the IPCC (2007), climate change is expected to have adverse effects on water resources across all regions of the world. According to Parry et al. (2007) stated that climate change is expected to increase the occurrence of floods and droughts in the Middle East and North Africa. In the same line the World Bank (2012) conducted an evaluation of the impact of climate change on water resources in Arab countries and suggested that efficient management of water resources is necessary to meet the increasing demand for water in the future. Climate change is also expected to lead to an increase in evapotranspiration, resulting in greater irrigation demand in the area. Water resources is also affected by the rise in sea level which will increase the risk of saline intrusion into groundwater and rivers, potentially affecting the quality of water and its usability for domestic, industrial, and agricultural purposes (Xu et al.,2007). The decrease in irrigation water supply due to insufficient rainfall also leads to a reduction in the areas under irrigated crops, possibly resulting in an increase in rain-fed crop areas in the following season, as reported by Kumar et al. (2004).

Impact of Temperature: As mentioned in the preceding section about the impact of global warming and climate change on rise in temperature which significantly affect agriculture in various ways. Soil moisture and nutrient availability, as well as nutrient use efficiency, are significantly affected by temperature increases due to their impact on the surface area of roots (Brouder and Volenec, 2008). The uptake of nutrients by plants occurs in solution form, and changes in climate affects alterations in soil temperature and moisture, which can greatly impact the conversion of organic and inorganic forms of nutrients in solution form through biological processes (Pendall et al., 2004). According to the UKMO GCM model as stated by Bhaskaran et al. (1995), there was an increase in total rainfall by about 20% and a temperature increase of 1-4°C during the winter or rabi crop season, along with an increase in CO_2 concentration. The net revenue was found to be affected significantly by changes in temperature and precipitation, which could be detrimental to crop production. Crops in warmer climates may experience faster growth, resulting in increased production and income. However, when temperatures are excessively low or high for an extended period, it can have detrimental effects on crop production (Mendelsohn et al.,1994). In the dry season, temperatures in high mountain regions can drop very low, with some records showing temperatures as low as -3.7 0C, according to reports by UNDP and IMHEN in 2015 and ISPONRE in 2009.

Although global warming is anticipated to result in more rainfall, the effect of higher temperatures on water availability is influenced by the competition between rainfall and evapotranspiration. As noted by Cline (2008), evapotranspiration generally wins this competition, reducing water availability. However, this may not be the case in certain regions. With climate change, irrigation water demand is expected to increase due to the need for more water per unit area. Additionally, pumping water will require more energy, which will raise the cost of irrigation, as highlighted by Rogelj et al. (1995).

Impact on Soil: The likelihood of soil infertility causing a decrease in both crop quantity and quality is elevated in India due to severe and inappropriate weather conditions. The climate shift is expected to impact various factors, including the replenishment of groundwater, moisture content in soil, and the occurrence of droughts and floods in different regions, as cited in studies by Allen et al. (2004), Eckhardt et al. (2003), and Huntington (2003). When soil temperature rises, it could result in a rise of autotrophic CO2 losses from the soil. These losses can be attributed to root respiration, root exudates, and fine-root turnover (Mahato, 2014).

The growth, development, and yield of crops can be determined through the utilization of crop models, which integrate diverse techniques such as soil chemistry, soil physics, agro-meteorology, plant breeding, crop physiology, and agronomy into a series of mathematical equations. This approach is described in studies by Aggarwal and Kalra (1994) and Hoogenboom (2000). To use climate change applications in crop modeling, long-term historical weather data is utilized. One approach to managing flood governance and promoting soil quality is to limit the number of rice crops and instead introduce hedgerows. These techniques are discussed in a study by Fischer and Hager (2005).

Impact of an increased level of CO_2 IPCC reports suggest that the production of C4 crops will increase by 0-10% and C3 crops will increase by 10-25% when CO2 levels reach 550ppm, based on recent data analysis (IPCC 2007b). According to a study by Adams et al. (1998), a 5°C increase in temperature, no increase in precipitation, and CO2 level of 530 ppm would result in a reduction of approximately $2 billion (1990 U.S. $) in welfare. However, Gautam and Kumar (2007) suggest that global agricultural production could benefit from the fertilization effect of increased CO_2 levels. Long et al. (2006) also support this idea, stating that while increased levels of CO_2 contribute to global warming, they may also be advantageous to plant growth and development.

The effects of increased CO_2 levels on agriculture should be taken into account along with other factors, such as changes in air temperature (especially at night), alterations in moisture availability, and their impact on plant growth and reproduction. Additionally, more farm resources, such as fertilizers, may be required, and pest populations may persist and spread, leading to a new balance between pests and crops (Krupa,2003). When there is an increase in the concentration of carbon dioxide (CO_2), plants can absorb more of it, which can lead to an increase in the rate of photosynthesis and the conversion of CO_2 into carbohydrates. However, plants may not have a quick response to the increase in CO_2, as long-term exposure to high concentrations of CO_2 can cause stomata to close (Elmassah and Omran, 2014).

Taub and Wang (2013) reported that rising atmospheric CO_2 concentrations lead to a decline in nutrient content within the edible tissues of most C3 plants, such as wheat, rice, and potato, as well as certain C4 plants, including sugarcane and maize. Heat waves can lead to a doubling of CO_2 levels, which can have negative impacts on farming. The impact of climate change on crop yields will vary across different regions of Sri Lanka, with the north and east receiving less rainfall than the central highlands. Crop predictions based on environmental and resource research indicate that wheat and rice yields in northwest India could increase by 28% and 15%, respectively, if CO_2 levels double from current levels (Ladrera and Cagasan, 2022).

Impact of increased Pests and Diseases: The reproductive cycle of insects and pests accelerates due to climate change, leading to a surge in their population. This surge in population necessitates an increase in the use of pesticides, which can have negative consequences on both the ecosystem and human society (Malla, 2008). The interaction between plants, pathogens, and the environment, known as the disease triangle, can be affected by climate change, leading to the spread of pathogens and negative impacts on plant populations and production potential (Andersen et al., 2018; Pathak et al., 2018). Climate change is expected to increase pathogen density, disease transmission, infection mechanisms, and host susceptibility (Abdullah et al., 2017). As a result, there may be an increase in outbreaks of viral and other diseases in the future (Jones, 2016). The changes in the incidence and distribution of pests and pathogens also have indirect effects. The variations in the patterns of pests and diseases with climate change can result in a decrease in agricultural production, as reported by Sutherst et al. (1995), increasing temperature and precipitation slightly may encourage diseases and insect pests (Mendelsohn et al. 1994).

Impact on Livestock: Climate change has negative impacts on animals, as highlighted in studies by Ngondjeb (2013) and Mishra (2014), and it can also harm the production of aquatic species. Richard et al. (1998) reported that livestock production could be affected in two ways due to climate change, with a potential decrease in the amount and quality of forage from steppe and direct impacts on livestock from higher temperatures. Adams et al.

(1998) estimated that a temperature increases of 1.5°C would result in a 1% yield loss in cow/calf and dairy operations in certain regions of the U.S., while a 5.0°C rise would lead to a 10% decrease. The production of livestock and processed food could also decrease with rising input costs, resulting in a decline of 5.9% and 4.6%, respectively, in global output, as discussed by Zhai and Zhuang (2012). Similarly, Richard et al. (1998) reported that climate change could result in alterations in the frequency, type, and intensity of pests affecting livestock and crops. Additionally, the availability and limitations of irrigation water supplies and the severity of soil erosion could also be affected by climate change.

During the dry season, lower temperatures can slow down or even damage crop growth, leading to a decline in overall crop production (Mendelsohn, 2014; Mahendra, 2011). The impact of annual temperature trends on net income is largely season-dependent; marginal temperature variations can have a significant influence, being beneficial in warmer conditions or detrimental in colder ones (Chen et al., 2016). According to Swaminathan et al. (2010), a temperature increases of 1 degree Celsius can cause a 4 to 5 percent reduction in wheat production. The International Monetary Fund (IMF) published a report in 2017 that found a 1degree Celsius increase in temperature would cause a 1.7% decrease in agricultural production in developing economies. In addition, a reduction of 100 millimetres of rainfall could result in a 0.35% decrease in growth.

Studies suggest that climate change will have a significant impact on agriculture in the coming years, as changes in temperature, precipitation, and greenhouse gases can negatively affect pests, soil fertility, irrigation, and plant processes. To address these challenges, various mitigation and adaptation strategies have been developed. These include the use of stress-tolerant crop varieties, ICT-based agrometeorological services, carbon emissions reduction, water conservation, yield increase, and innovative irrigation techniques like raised beds and direct-seeded rice. These measures aim to reduce greenhouse gas emissions and minimize the negative effects of climate change on agricultural sustainability. To mitigate and adapt to climate change in agriculture, measures such as value-added weather services, integrated pest management, plant breeding for climate-resilient crops, efficient water use, and resource conservation technologies must be implemented.

II. Conclusion

The harsh reality of climate change requires timely and appropriate action. The increasing concentration of CO_2 and temperature variations, along with other environmental factors, poses a significant threat to agriculture worldwide. Climate change-induced drought and heat stress are among the primary factors leading to yield and productivity losses, with developing countries experiencing more negative effects. Climate change affects agriculture by altering critical factors such as precipitation, CO_2 concentration, and temperature, which are essential for plant growth and development. The impact of climate change on agriculture is distressing and difficult to overcome, with uncertainty and a lack of information about tackling this problem. The overall effects of climate change, including both positive and negative impacts, can be considered opportunities and costs. While positive impacts may present opportunities in certain areas, negative impacts can increase the cost of compensating for changes in agriculture. Therefore, it is essential to develop strategies that maximize opportunities and minimize costs for sustainable agricultural development.

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