

# The Impact of Climate on Crop Production

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## ABSTRACT

Climate change poses a growing threat to global agricultural productivity, particularly in regions already exposed to high temperatures and water stress. This paper examines the relationship between climate variables and crop production in Brazil, a major global agricultural producer. Our analysis uses municipality-level production data combined with satellite-based climate measures. We hypothesized that if variables like temperature, humidity, and nitrogen monoxide (NO) levels differed, then crop production would also change. Our analysis revealed that, generally, as temperature, humidity, and pollution levels increase, crop production outcomes decrease across multiple crop types. Specifically, the fitted curves show different patterns in crop production across temperature, humidity, and pollution levels. Based on the literature review, regions with greater access to agricultural technologies exhibit reduced production volatility, indicating that technological adaptation may partially offset climate-induced losses. Therefore, we discuss how our findings implicate technological adoption for mitigation of adverse climate effects, highlighting the importance of targeted technology diffusion and climate forecasting tools in sustaining agricultural output under future climate change scenarios.

## INTRODUCTION

This study investigates how different environmental factors, such as temperature, humidity, soil, and pollution, might affect crop production. By combining a literature review with a regression analysis using Brazilian data on climate and production, we find that crop production responds nonlinearly to environmental factors and declines significantly beyond specific levels. We lean on existing literature to help highlight how increased adoption of agricultural technologies can support the mitigation of these negative effects and improve long-term farm productivity under climate change.

Several studies have looked at the impact of individual aspects of climate change on crop yields. For example, Ceglar et al. (2017) have examined how temperature extremes cause crop failure or how precipitation may increase or decrease crop growth (1). These studies often focus on specific environmental factors, motivating us to compare how several of our environmental variables are individually associated with crop production. In this research, we will evaluate the extent to which external factors, such as pollution and climate change, are associated with agricultural crop production.

Much of the existing literature examines crop yield, which measures output relative to harvested area, whereas our empirical analysis examines total crop production at the municipality level. Yield and production are related but not equivalent: changes in yield can affect total production, while production

may also reflect differences in harvested area, farming practices, technology, and other production decisions. We therefore use the yield literature to identify relevant mechanisms and expected environmental relationships, while our empirical analysis examines whether similar patterns are observed in total crop production across Brazilian municipalities. Similarities between the two should be interpreted as consistent patterns rather than direct estimates of yield effects.

Our study examines several environmental factors individually to compare their relationships with crop production. Although farmers experience multiple environmental factors and technological differences simultaneously, these factors are not analyzed together in our regression models. Agricultural technology is discussed separately through our literature review as a potential adaptation strategy identified by prior research, but technology adoption is not directly measured in our dataset. This perspective is important for developing effective adaptation strategies that can better protect food production under changing climate conditions. Our analysis focuses on temperature, humidity, and nitrogen monoxide (NO), while our literature review discusses additional factors including water availability, soil conditions, and agricultural technology.

Temperature is arguably the most important factor due to climate change and global warming. Climate change is critical when it comes to crop production. This is because warmer temperatures and drastic weather events make it difficult to cultivate and grow crops. Another factor is water, because water is required for all crops. If a crop does not receive the exact amount required, then it cannot grow to its maximum potential. With environmental changes such as droughts, most crops cannot receive the water they require. Soil is another key factor because climate change has made soil less fertile and less suitable for different crop varieties. Soil provides nutrients and anchorage to crops, which is important for growth. Finally, pollution is also important because it can restrict the growth and production of crops; examples of pollution include NO and ozone (O<sub>3</sub>). Reducing the amount of pollution is necessary if we want to see an increase in crop production. Technology is another important factor to consider, since technologies and their adoption rates are fundamental to allowing farmers to produce crops. In this study, we hypothesized that if variables like temperature, humidity, and nitrogen oxide levels differed, then crop production for banana, coffee, and oranges would also change.

## **LITERATURE REVIEW**

This section is separated into parts for each factor affecting crop production.

### **Temperature**

Global warming is the most anticipated factor for crop production in the future, as it greatly affects how crops grow. Schillerberg and Tian (2023) showed that temperatures are likely to increase severely in the next decade due to climate change (2). All crops grow best in their specific temperature range, and when the temperature fluctuates or changes, this will cause changes in crop yields. Due to changes in climate, crop producers will need to adapt and figure out ways to combat this global phenomenon. One prediction

that we could make about global warming is that it is possible farmers will need to switch to crops that can grow at higher temperatures.

A simple prediction model by Ceglar et al. (2017) shows wind currents resulting from climate change can explain 70% of the total crop failures in any given year. Farmers can use this information to understand when harmful wind patterns occur and take steps to reduce damage and maximize yield. Their results also show that different countries seem to be affected differently by climate change. The US crop yields will decrease with a changing climate, but Canada's crop yields will increase with changes in the climate. This is because U.S rising temperatures and increased droughts will move conditions beyond the optimal range for many crops, while Canada will experience gains as warming creates longer growing seasons and more favorable conditions in previously cooler regions (1).

Schillerberg and Tian (2023) analyzed global crop failure events using satellite and climate data to examine how climate influences widespread yield losses. They used machine learning to predict failures from variables such as temperature and moisture. They showed that large-scale crop failures are strongly tied to climate variability. The study also included both maize and wheat, which are grown on one-third of farms globally. Although yields of both wheat and maize is expected to decrease by 4-5% per year due to climate change, the article also predicts that maize will overtake wheat as the most widely grown crop by area by 2030 (2).

A specific example of large-scale climate variability is the rise in average temperature in India due to monsoons. The annual minimum temperature in India has been shown to rise about 0.24 degrees Celsius per decade. About 57.2% of kharif yields (crops planted before monsoon) were influenced by this increase in temperature. This is only one example of how crop production can be affected by climate change and increasing temperatures around the world (3).

This large-scale climate variability and rise in global temperatures mean we are likely to see food shortages in several major farming regions around the world. According to Gaupp et al. (2019), wheat, maize, and soybean production have all been projected to decrease significantly when there is a 1.5 to 2 degrees Celsius increase in global warming (4).

## **Water**

One major side effect of large-scale climate variability and rising global temperatures is reduced water availability and increased water demand for crops. If crops receive insufficient or excessive water, their growth is negatively affected. Providing the proper amount of water is essential for crops to reach their full production potential.

The agricultural sector is most susceptible to changes in the climate and water availability, as it is the highest consumer of water. Ceglar et al. (2017) predicted that crop yield failure probability due to water shortage is expected to be 4.5 times higher in 2030 and 25 times higher in 2050. They have found a positive relationship between water scarcity and crop yield failures (1).

The effect of water scarcity on these plants is that shortages during the growth stage can also result in reduced plant height and leaf size. The highest crop yields are observed when there is full irrigated

control. If there is even a single irrigation omission during one of the sensitive growth stages, then it can result in up to 40% grain yield losses (5).

However, to combat this increase in water scarcity, Adeoti and Adetola (2008) focus on traditional irrigation methods in Ghana and how treadle pump technology was promoted to replace the traditional irrigation methods there. The two factors that increase the adoption rates for this technology are the number of extension visits per year and the availability of labor. The results show that expanding irrigation helps farmers earn more stable and higher incomes, which reduces poverty levels (6). This study is one of many examples that show that we can adopt new irrigation technologies and techniques as a way to combat climate change.

Unfortunately, if these new emerging technologies and methods are insufficient against the effects of climate change, Song et al. (2018) found that droughts affect plant and leaf growth and photosynthesis. After droughts, rewatering doesn't help restore leaf functions to normal levels. This study helped provide insight into managing drought effects and improving crop strength against climate change (7). It also shows us how, through climate change, whether rainfall or droughts, these events damage crops and cause them to suffer. Adding the fact that re-watering doesn't restore leaf functions to normal, this means that the damage is irreversible.

Swami et al. (2018) found that monsoon variability has a huge effect on Indian agriculture. The Monsoon variability index, which measures how much the timing and amount of monsoon rainfall change from year to year, showed that the districts of Vidarbha and Marathwada are at the highest risk from monsoons. The index can also help determine the ideal cropping pattern for the most monsoon-vulnerable district (8).

## **Soil**

Climate change is predicted to create worse conditions for most aspects of farming and crop production, including soil. It has been seen that climate change is creating hotter and more humid conditions, which can cause soil to become less fertile or not contain the amount of nutrients that it should. It is not just climate change but also increasing external factors such as growing populations that can affect the quality of soil. These are causing farmers to plant more crops just to keep up with the growing demand, leading to soil degradation. Soil is essential for crops because it supplies nutrients and physical support needed for growth. Without healthy soil, crops cannot develop properly or reach their full production potential.

These pressures on soil can be seen in agricultural regions around the world. The paper by Dalton et al. (2011) examines how factors in Southeast Asia such as population pressure, land use restrictions, and tenure insecurity cause unsustainable agricultural practices and land degradation (9). These factors can lead to harmful farming practices because they increase the pressure on farmers to produce more crops in order to earn enough income. As these external pressures grow, farmers may tend to prioritize short-term productivity over long-term land sustainability. This leaves less opportunity to focus on preserving soil health and the future viability of their farms. This paper argues that conservation efforts should not just encourage farmers to adopt technologies but also to address farmers' health and reduce the pressure on fragile lands.

Technology plays a critical role in maintaining soil health and ensuring long-term land productivity. Dalton et al. (2011) found that farmers involved in participatory research were significantly more likely to adopt soil-conserving practices such as hedgerows and contour ridging, both of which reduce erosion, improve soil structure, and enhance nutrient retention. Participatory research involves the direct collaboration of farmers in testing and evaluating new agricultural practices under real field conditions. By participating in the study, farmers were able to directly observe how these soil management techniques improved soil stability and fertility, increasing their understanding of the practices and their confidence in the long-term benefits (9).

Beyond improving the soil conditions, the study also demonstrates that these innovations influence land use decisions and cassava yield by promoting more sustainable soil management. Importantly, participation in the research process itself was associated with improved cassava yields, even when farmers did not fully adopt the new technologies. This suggests that experiential learning and increased awareness of soil conservation practices can strengthen soil management strategies and improve productivity, independent of complete technological adoption.

## **Pollution**

Pollutions such as air pollution, water pollution, and soil pollution are all types of pollution that are harmful and a major threat to crops. We want to minimize pollution to allow crops to grow and thrive. Nitrogen Dioxide (NO<sub>2</sub>) is a widely emitted pollutant that negatively affects crop production.

The effect of this pollution on crops can be seen in previous research by Lobell et al. (2022). This study finds a negative relationship between NO<sub>2</sub> and greenness across the United States during different seasons. They estimate that reducing the NO<sub>2</sub> levels to the fifth percentile in each region would raise crop yields by 25% during winter and 15% during summer (10).

The pollution measure used in our empirical analysis differs from the NO<sub>2</sub> measure examined by Lobell et al. (2022). Our dataset uses nitrogen monoxide (NO), while Lobell et al. examine nitrogen dioxide (NO<sub>2</sub>). Although both are nitrogen oxides associated with air pollution, they are distinct pollutants. We therefore use the NO<sub>2</sub> literature as broader evidence on how nitrogen-oxide pollution may affect agriculture, rather than as a direct comparison with our NO-based results.

The research by Lobell et al. (2022) also takes a look at the ozone (O<sub>3</sub>) effect on crops. Through their predictions, they find that by 2030, the O<sub>3</sub> effect on crops will cause huge reduction rates in production, such as a 5.4-26% reduction rate for wheat and a 15-19% reduction rate for soybeans across the U.S Midwest. The findings rest on the idea that if we keep emitting the same amount of pollution without any efforts to contain it, then we will see huge crop yield reductions in the future.

## **Technology**

Technology is what allows farmers and other crop cultivators to maintain their crops and maximize production. Examples of useful technologies in agriculture are crop rotation, biotechnology, and automation. Technology plays a major role in crop production as it allows increased yields and efficiency. Although this study did not directly measure the effects of specific technologies, it is still an important factor to consider and discuss. Prior research on technology adoption suggests that tools such as improved irrigation systems and climate forecasting methods may reduce yield volatility and enhance resilience. This section further explores the extent to which technological adaptation may mitigate these effects.

However, the benefits of these technologies depend on whether farmers are actually able to adopt them. As shown by Ruzzante et al. (2021), low adoption rates of agricultural technologies are largely driven by barriers such as limited education, lack of access to information and extension services, restricted access to credit, insecure land tenure, and limited participation in farmer organizations. These institutional and informational constraints reduce farmers' ability and willingness to adopt new technologies (11).

The first factor is lack of education, which gives farmers the necessary knowledge on how to use different technologies. If farmers had been educated, then they would be more likely to adopt different technologies. Like education, information services also affect technology adoption rates because they show farmers how to use a certain technology, making it easier to adopt new technologies. Another important factor influencing technology adoption is household size. Larger households often require higher levels of agricultural production to meet consumption needs, which can encourage farmers to adopt beneficial technologies. Additionally, having more individuals within a household increases the likelihood that at least one member has the knowledge needed to implement new technologies. Organization membership also plays a significant role in adoption rates. Farmers who are part of agricultural organizations or cooperatives have greater access to shared resources and knowledge. These connections allow them to seek guidance and learn from the experiences of other farmers when adopting new technologies.

These barriers can be seen in practice in developing agricultural regions. A study conducted by Adeoti (2008) shows that adoption rates of agricultural technologies in Ghana remain relatively low, even though these technologies play a major role in improving crop production. This gap between availability and utilization highlights barriers that limit farmers' ability to implement productivity innovations. To achieve sustained increases in crop production, agricultural technologies must become more accessible and economically feasible for farmers.

Improving access to credit, education, farm size, and land security can collectively improve adoption rates. Addressing these barriers promotes technology adoption and contributes to long-term farm productivity (6).

In addition to technology adoption, climate predictability also plays an important role in improving crop outcomes. Ceglar et al. (2017) analyzed European crop yield data together with climate variables and large-scale atmospheric patterns. Using a statistical model approach, they quantified the relationship

between atmospheric circulation and yield variability, finding that circulation patterns explain up to 70% of interannual crop yield variability in parts of Europe. These results demonstrate a strong link between large-scale atmospheric circulation and crop yields, suggesting that preceding atmospheric conditions provide a meaningful source of seasonal predictability (1).

Because large-scale atmospheric patterns are generally more predictable than short-term weather variables such as daily temperature or precipitation, incorporating this information into forecasting systems can substantially improve seasonal crop yield predictions. From a technological perspective, this creates opportunities to integrate climate models into digital support tools, agriculture platforms, and farm management software. By embedding large-scale climate forecasts into these technologies, farmers can make more informed decisions regarding when to plant crops, crop selection, irrigation planning, and crop risk management strategies.

Advances in climate-based predictive modeling complement agricultural technology adoption, enhancing resilience and improving crop productivity.

## **METHODS & MATERIALS**

Our initial approach to answering the extent to which external factors are associated with crop production is through a literature review. We synthesized eleven research papers to help us understand how environmental factors may be associated with changes in crop production.

We then examined whether patterns suggested by the existing crop-yield literature were also observable in municipality-level crop production data from Brazil. We selected data from Brazil because they are a major global agricultural producer, which makes the data relevant and important. Additionally, Brazil contains agricultural regions that are exposed to warm climate conditions, making it useful for examining associations between environmental conditions like temperature and crop production.

In our analysis, we used two dynamic data sources from Brazil that cover environmental and crop production factors. We examined the relationship between crop production and temperature, humidity, and nitrogen monoxide levels, analyzing each factor separately to understand how production levels change.

Our data came from Pesquisa Agrícola Municipal (PAM), which tracks crop production in each municipality. We merged this with satellite data on climate and atmospheric conditions from 2016 to 2022 to construct a granular view that helps us distinguish the production of individual crops and understand differences between species.

This data was used to draw a quadratic trendline using a logarithmic regression, where crop production was the dependent variable and temperature, humidity, and nitrogen monoxide levels were the independent variables. We favored a quadratic trendline over a linear trendline because it can better capture nonlinear patterns, such as increases followed by decreases in production, that wouldn't be represented by a simple linear graph. For example, we found that orange production generally increases as temperature rises before declining at higher temperatures. In this case, a linear graph may not capture this change in data, as it only shows a general trend.

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To perform the regression, we first log-transformed the production values to better capture changes in crop production. We then regressed the log production against our factors of temperature, humidity, and nitrogen monoxide levels separately for each crop (i.e., banana, coffee, orange) as shown in the regression equations below. Using a quadratic model in our logarithmic regression, we captured curves in the data showing ranges where production appeared high or low and points where the fitted curves began to decline.

$$\ln(Y_{ip}) = \beta_0 + \beta_1 T_{ip} + \beta_2 T_{ip}^2 + \varepsilon_{ip}$$

$$\ln(Y_{ip}) = \beta_0 + \beta_1 H_{ip} + \beta_2 H_{ip}^2 + \varepsilon_{ip}$$

$$\ln(Y_{ip}) = \beta_0 + \beta_1 NO_{ip} + \beta_2 NO_{ip}^2 + \varepsilon_{ip}$$

where  $Y_{ip}$  is the production as defined below for municipality  $i$  and product  $p$ ;

$T_{ip}$  is the Temperature for municipality  $i$  and product  $p$ ;

$NO_{ip}$  is the Nitrogen Monoxide level for municipality  $i$  and product  $p$ ;

$H_{ip}$  is the Humidity for municipality  $i$  and product  $p$ ;

$\varepsilon_{ip}$  is the error term for municipality  $i$  and product  $p$ .

Log Production is the natural log of the quantity produced, measured in metric tons

One limitation of this research is that most of the agricultural production data comes from Brazil. Although Brazil is a major producer of several crops, relying on data from a single country makes it difficult to generalize the findings to other regions. Another limitation is that the analysis focused primarily on revealing relationships between crop production and environmental factors. Because we could not conduct experimental analysis, the results emphasize overall trends rather than establishing causal claims between variables.

## RESULTS

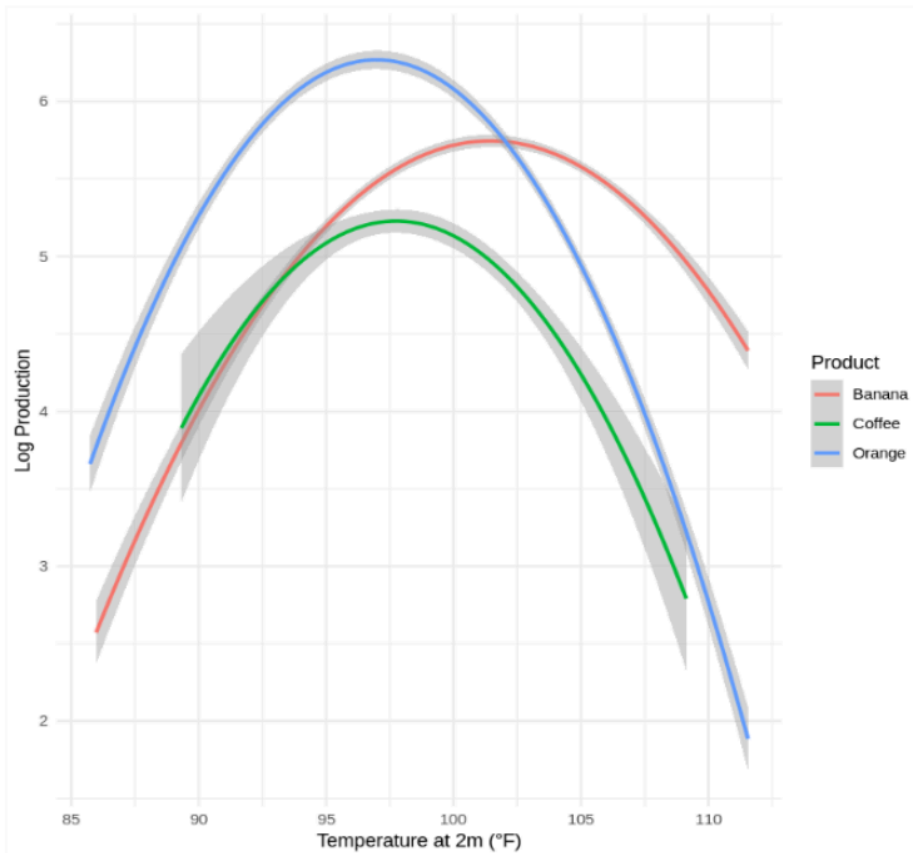
We selected the three crops, bananas, coffee, and oranges, because they are important agricultural products in Brazil and could respond differently to environmental conditions. Using these three crops allows the analysis to compare whether temperature, humidity, and nitrogen monoxide affect crop production in similar or different ways. Because the outcome variable is total production, the fitted relationships below describe associations with crop production rather than direct changes in yield per unit of land.

### Temperature and Crop Production

The temperature graph showed a nonlinear association between temperature and crop production. Within the observed data, higher production in bananas was generally associated with warmer temperatures. This suggests that bananas are better suited to warmer growing environments. In comparison, coffee and orange production rose through much of the observed temperature range and appeared to peak around

105-110 degrees Fahrenheit before beginning to decline at more extreme temperatures. This curved pattern suggests that warmer conditions may initially support crop growth, but only up to a certain optimal range for that crop. Above these observed ranges, the fitted curves generally declined. Previous research suggests that heat stress may contribute to reductions in crop productivity at these high temperatures. The decline in curves for all three crops at the highest observed temperatures is important because it signals that gradual warming could eventually negatively affect crops that normally grow well in warmer climates.

**Figure 1: Crop Production in Different Temperatures**

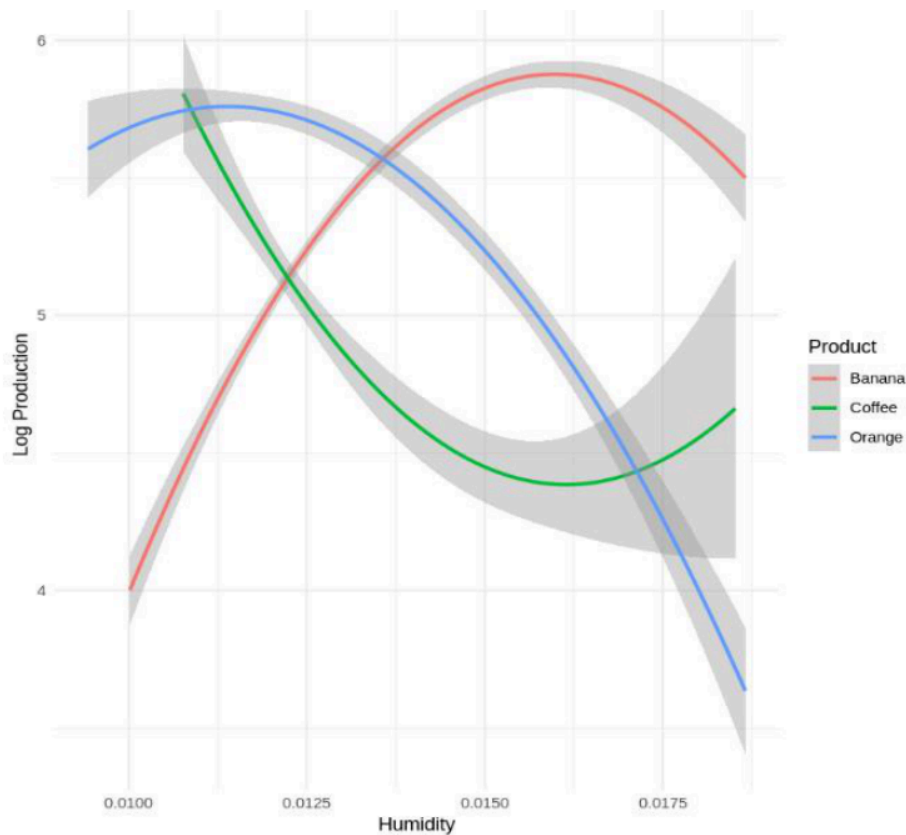


### **Humidity and Crop Production**

Figure 2 shows the amount of production between different crops at different humidity levels. For example, bananas are shown to grow better at higher humidity levels and worse at lower humidity levels. Coffee shows the inverse of this, growing better at lower humidity levels and worse at higher humidity levels. Orange production, on the other hand, decreases as humidity gets higher but begins to increase again as the humidity reaches extremes. As shown in the graph, the fitted curves show lower production at some higher or lower humidity levels, depending on the crop.

This result can be seen as reasonable because generally, bananas require a large amount of water and commonly grow in warm environments. Coffee showed an opposite pattern, with production performing better at lower humidity levels. This underscores that excessive moisture can create bad conditions for coffee plants. Orange production showed a mix of the previous two crop production patterns. Initially, it decreased as humidity increased but began to rise again at the most extreme levels of humidity. This curved relationship shows that oranges are able to withstand multiple humidity conditions.

**Figure 2: Crop Production in Different Humidity Levels**



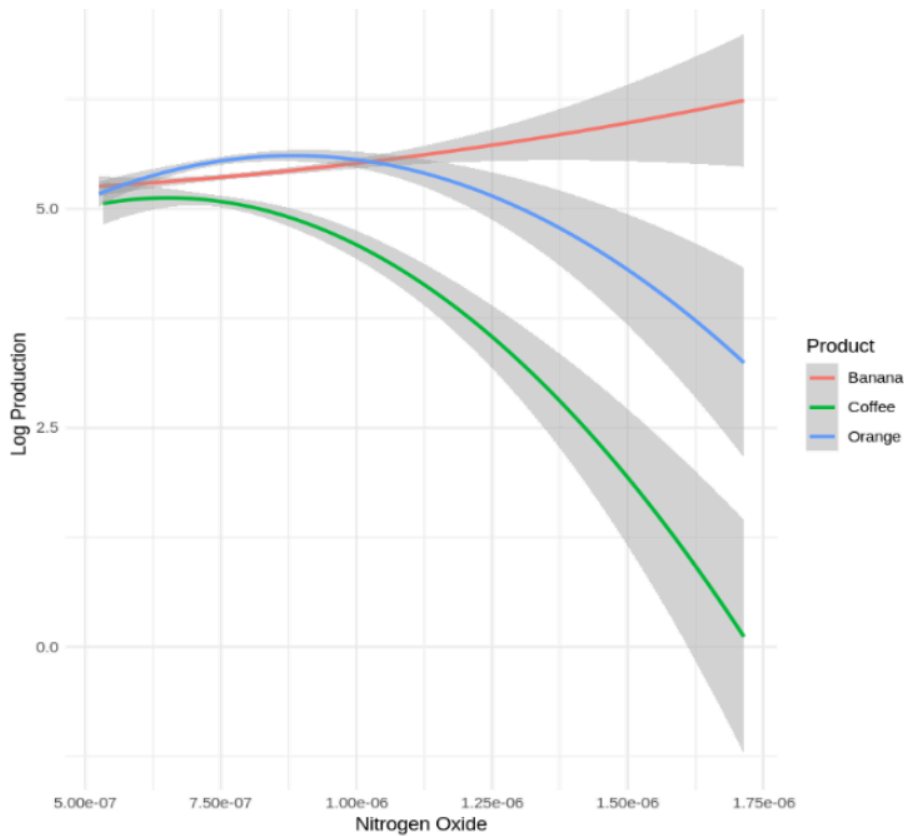
### **Nitrogen Monoxide and Crop Production**

Figure 3 shows how different levels of nitrogen monoxide (NO) affect production levels of Bananas, Coffee Beans, and Oranges. As shown by the graph, with increasing NO levels, coffee bean and orange production rates decrease. On the other hand, bananas show a steady increase in production rates with higher NO levels.

The nitrogen monoxide graph examines how pollution can affect the production of these three crops. Coffee and orange production declined as the NO levels increased, which suggests that these crops are

negatively affected by higher levels of pollution. NO can lead to poor air quality and the formation of ground-level ozone, which can therefore result in damage to plant tissue and affect photosynthesis. Because of this, increased pollution can reduce the ability of coffee and orange plants to grow efficiently. In contrast, banana production increased as the NO levels rose. This doesn't necessarily mean that NO directly causes the improvement of banana growth. This pattern may reflect other factors associated with the locations where the bananas were produced, such as temperature, rainfall, soil conditions, or different uses of agricultural technology. Because the analysis measures the correlation, not the causation, this depiction of the banana growth trend should be interpreted cautiously.

**Figure 3: Crop Production in Different Nitrogen Monoxide Levels**



## CONCLUSION

By reviewing studies on factors shaping crop production, this paper provides preliminary findings that show the relationships between climate and crop production while discussing implications of technology in agriculture. While the study is limited by data constraints and the correlational nature of the chosen analysis, it also focuses on a narrow number of agricultural products. This limits how much the findings

can be applied across crop types. Despite these constraints, the literature review suggests the role of targeted technology diffusion as a potential strategy for sustaining agricultural productivity under climate change.

The results indicate that crop production exhibits nonlinear responses to temperature, humidity, and pollution, with production declining sharply beyond crop-specific thresholds. The graphs used in this study suggest that crop production does not respond to environmental factors in a simple linear way.

For coffee, oranges, and bananas, temperature, humidity, and NO levels were each associated with different changes in production. Some graphs show production increasing to a certain point before slowing down or decreasing, which suggests that crops may have optimal environmental ranges. However, since this analysis is correlational and based mainly on Brazilian data, the graphs do not necessarily prove that these factors directly caused changes in production. Other factors such as farming methods, irrigation, and technology may also explain the patterns shown. The pollution results also require careful interpretation because our empirical analysis uses NO, while some of the supporting literature examines NO<sub>2</sub>. The NO findings should therefore be viewed as associations with a related nitrogen-oxide pollutant rather than as direct confirmation of previously reported NO<sub>2</sub> effects. Future research could compare multiple nitrogen-oxide measures to determine whether these production patterns are consistent across pollution indicators.

These findings align with existing literature on climate sensitivity in agriculture and underscore the risks posed by increasing climate volatility. Rather than affecting all the crops equally, these climate factors have varying thresholds where the conditions change from helpful to harmful for the crop. This highlights that losses in crop production do not tend to occur gradually but happen more severely when the environmental conditions surpass the limits. Because Brazil is a major worldwide producer of agricultural products, the patterns that are being depicted should begin to raise concerns about the stability of our food supply due to increasing environmental extremes and the need for adaptation. This argues for the need for adoption of new agricultural technologies to combat these concerning environmental conditions.

Future research could extend this analysis by incorporating direct measures of technology adoption or expanding the dataset to additional countries and products.

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