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Burning Sweetness: Analyzing the Impact of High Heat Index on Yield and Provincial Contributions in the Sugarcane Industry of the Philippines

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Abstract

This study examines how the Philippines' heat index affects the country's sugarcane production, concentrating on the provinces of Negros Occidental and Negros Oriental, which are important to the nation's sugar sector. The growth of sugarcane has been badly impacted by rising temperatures brought on by climate change, which has resulted in a gradual drop in production. This study evaluates the relationship between heat index and sugarcane yield using data from November 2022 to June 2024. It does this by using a mathematical formula to calculate the heat index's Rate of Negative Impact (RNI). Taking into account a threshold temperature of 25°C, which is ideal for sugarcane development, the formula is utilized to determine the new contribution percentages of each province to the overall sugar sector. The findings show a clear relationship between decreasing productivity and rising heat indices. For instance, in Negros Occidental, the province's share decreased from 43.2% in November 2022 to 24% by June 2024 as a result of the heat index rising above recommended levels. Similar trends were seen in Negros Oriental, where donations decreased from 7.6% in November 2023 to 3.6% in May 2024. These results demonstrate how sensitive sugarcane production is to temperature increases, demonstrating that greater heat indices result in lower yields and detrimental effects on the economies of communities that depend on this industry. To ensure the sustainability of the sugarcane sector and the livelihood of people who depend on its success, this study emphasizes the significance of climate adaption measures.

Keywords: Sugarcane production, Heat Index in Negros Oriental and Negros Occidental, Yield, Mathematical Computation

Introduction

Mathematics provides a wide range of methods to aid in addressing our environmental issues. They provide practical answers for predicting significant occurrences, simulating complex phenomena, and maximizing natural resources. Significant progress in addressing environmental issues is made possible by ongoing research in this area. These real-world uses are demonstrated by websites such as the use of mathematics in daily life and the complex nature of fractals (Lefevre, 2025).

In the same way, mathematics also plays an important role in industries that shape the Philippine economy. The Philippines sugar industry. The sugar industry remains extremely important in the national economy. Most of the output of the sugar industry now serves the domestic needs of Philippine consumers and producers. Almost all sugar produced in the country is consumed locally. The sugar industry today is very different from the sugar industry of old. It is one that practically serves only the domestic market, although it pretends to be an export surplus industry. Sugarcane is one of the most important industrial crops in the world. The Philippines ranked eighth (8th) in the world on production volume with 32.46 million metric tons.

However, like any other agricultural commodity, low productivity is one key issue that beset the sugar industry. Comparing Philippines with other Southeast Asian countries such as Thailand (sugarcane production is 100-ton canes per hectare), the country has low productivity which is estimated at 60-ton canes per hectare. The effects of climate change such as higher temperatures and drier conditions contributed to low yield (Cpredo, 2025).

Western Visayas continued to be the top sugarcane-producing region with 1.34 million metric tons or 47.2 percent share to total production for this quarter. This was followed by Northern Mindanao and Central Visayas with corresponding productions of 516.79 thousand metric tons (18.3%) and 355.41 thousand metric tons (12.6%). These regions contributed 78.1 percent of the country's total sugarcane production (Authentication Challenge Pages, n.d.-b).

However, the increasing frequency and intensity of extreme weather events due to climate change pose a substantial threat to sugarcane production. The effects of climatic change are more noticeable in all stages of sugarcane growth, including germination, tillering, grand growth, and maturity phases. From January to June 2023, the area harvested for sugarcane was 212.34 thousand hectares, which indicates a decline of -12.6 percent compared with the same period of 2022 level of 242.84 thousand hectares. Majority of the reported area for sugarcane was for centrifugal sugar with 207.02 thousand hectares (Authentication Challenge Pages, n.d.-b).

Sugarcane production has decreased by 10.7%, from 26, 277, 400 metric tons in 2021 down to 23, 455, 400 metric tons for the year 2022. In 2023, a 7.7% decrease on sugarcane production was also recorded by the DA, from 23, 455, 400 metric tons down to 21, 649, 100 metric tons of sugarcane (DA FY 2023 Annual Report.pdf, n.d.).

These figures highlight the growing vulnerability of industry to environmental and climatic factors, underscoring the need for more systematic approaches in addressing such challenges. Research that specifically investigates the impact of the heat index on sugarcane yields in the Philippines is still lacking, even though numerous studies have examined the effects of climate change on agricultural production. Few studies concentrate on the combined effects of heat and humidity, especially in important sugar-producing districts like Negros Oriental and Negros Occidental. Most existing literature addresses temperature, rainfall, and drought in broad terms. This is where mathematics becomes an essential tool. According to Lefevre (2025), the application of mathematics is important for understanding and solving environmental issues. The investigation of complex phenomena like climate change, natural resource management, and the effects of human activity on ecosystems is made possible by predictive models and equations. To predict future problems and create sustainable solutions, mathematics plays a crucial role by offering the means to study, simulate, and comprehend the interactions that occur in our surroundings.

In this study, the researchers have to determine the effects of heat index on sugarcane production, whether it increases or decreases based on the heat index. With mathematical results and models, the researchers aim to determine the sugarcane production under a certain heat index.

Understanding this relationship is not only central to the study's objectives but also highlights its broader importance. The significance of this study is to help us know how the heat index can affect the production of sugarcane. Whereas, if the heat index were higher than usual, then the production of sugarcane would decrease; on the other hand, if the heat index were lower or normal, then production would increase or stay at its normal percentage of production.

Literature Review

The growth of sugarcane is highly dependent on temperature, with the ideal range considered to be between 30 and 35°C. Within this range, the plant thrives and maintains efficient physiological processes necessary for growth and sucrose accumulation. However, prolonged hot and dry conditions can cause leaf wilting, soil drying, and internal stress. When temperatures rise above 40°C during extended heatwaves, sugarcane's physiological functions begin to deteriorate. Heat stress accelerates respiration, which depletes the plant's energy stores, leaving less available for growth and sugar storage. Furthermore, oxidative stress initiates damaging biochemical reactions that further disrupt normal plant functioning, leading to lower productivity (Heat Stress in Sugarcane | SASRI, n.d.).

These physiological changes highlight the vulnerability of sugarcane to heat stress despite its natural adaptation to warm climates. Excessive respiration, while essential for producing active energy from stored reserves, becomes counterproductive under heat stress as it drains the plant's resources. The resulting imbalance reduces the stalk's sucrose storage capacity and overall energy available for survival and reproduction. Moreover, oxidative stress alters key cellular processes, compounding the negative effects of high temperatures. As such, sugarcane growth and development are significantly compromised once temperatures exceed the crop's maximum tolerance, threatening both quantity and quality of yields.

Technological tools such as remote sensing have been employed to investigate the effects of heat stress on crops. Remote sensing offers valuable data on crop conditions, but its ability to isolate heat stress independently of other factors like water scarcity and light limitation remains limited. These challenges hinder accurate assessments of gross primary production (GPP) and yield estimation. Recent studies, however, have worked on developing innovative approaches to distinguish true heat stress periods from normal growth conditions, offering potential improvements for agricultural monitoring and management. Accurate detection and attribution of stressors are therefore critical for designing adaptive strategies under a changing climate.

Heat stress is widely recognized as a major constraint to crop productivity. According to Sandhu et al. (2018), it significantly hinders plant growth and development, ultimately lowering crop yields. Aneja et al. (2022) further emphasize that rising global temperatures impair key physiological processes essential for plant survival and productivity, contributing to the global decline in yields. One particularly critical stage is flowering, where exposure to extreme heat drastically limits reproductive success and yield potential. With climate change driving more frequent and intense heatwaves, the impacts of heat stress are expected to intensify, posing greater risks to global food security.

To counter these challenges, agronomic adjustments have been recommended to reduce vulnerability during sensitive growth stages. One common adaptation is adjusting sowing dates, such as planting summer crops earlier in late winter or early spring, to minimize overlap between drought, heat stress, and critical flowering periods. Additionally, crop management practices in rice fallow conditions utilize residual soil moisture left from previous crops, providing temporary protection against water stress. In such contexts, short-duration and drought-tolerant varieties are preferred to maximize yield within the available moisture window. These strategies reflect how farmers adapt biologically and technologically to mitigate overlapping stresses.

The ability of farmers to adapt, however, is largely shaped by socioeconomic conditions. High temperatures not only reduce crop productivity but also negatively impact labor capacity, forcing changes in farming practices and livelihood strategies. Orlov et al. (2021) and El Khayat et al. (2022) point out that heat stress influences both agricultural output and worker productivity, while Baldoni et al. (2018) and Aragón et al. (2021) emphasize the importance of micro-level statistics in capturing the diverse responses of farmers to stress. These socioeconomic factors underscore the complexity of agricultural adaptation, as successful responses require not only technical solutions but also resources, knowledge, and institutional support.

Focusing specifically on sugarcane, Sanghera (2020) highlights that deviations from the ideal temperature range reduce yields by altering physiology, biochemistry, and quality, ultimately leading to poor agronomic performance. Both high and low temperature stress negatively affect sugarcane's ratoon ability, germination rate, and seedling establishment. Numerous experiments confirm that sugarcane yield is highly sensitive to temperature stress, necessitating targeted interventions. Effective heat-risk mitigation, therefore, lies in combining improved detection and attribution methods, such as advanced remote sensing, with stage-aware agronomy and locally feasible socioeconomic support, including access to stress-tolerant varieties, advisory services, and timing tools. Together, these approaches provide a comprehensive framework for minimizing the adverse effects of heat stress on sugarcane and other crops.

Rising global temperatures not only impair plant functioning and reduce yields but also increase the vulnerability of farmers whose adaptive capacity depends on resources and institutional support. While advances in detection methods and agronomic practices offer potential solutions, their success hinges on integrating technological innovation with locally adapted management strategies. As highlighted by Lobell et al. (2011), addressing climate-induced stresses in agriculture requires a holistic approach that combines improved monitoring, targeted interventions, and policies that enhance farmer resilience. Thus, sustainable sugarcane production under climate change will depend on bridging physiological insights, precision technologies, and socioeconomic realities to mitigate the compounding effects of heat stress.

Methodology

This study utilizes a quantitative–descriptive–computational research design. In several fields, from science and engineering to finance and healthcare, computational mathematics is essential to the solution of challenging issues. Complex system modeling, simulation, and analysis are made possible by this diverse field's combination of mathematical concepts and computing methods. In this course, we will go over fundamental concepts and procedures of computational mathematics and show how it may be used to solve problems in the real world. Computational methods are crucial for deriving significant patterns and insights from the massive volumes of data collected across numerous areas. Computational techniques used in data analysis include algorithms for anomaly detection, regression, classification, and data clustering. To train models, make predictions, and learn from data, machine learning algorithms—which are essential to artificial intelligence—heavily rely on computational mathematics (Savio, 2023).

By using mathematical modeling techniques like regression analysis and prediction equations, the researchers want to find out if changes in the heat index are connected with higher or lower sugarcane yield. Through the use of numerical evidence and forecasts, this approach enables the study to not only define the effects of climate change but also to anticipate future scenarios of sugarcane production under various heat index situations. Mathematical tools are thus essential for converting agricultural and climate data into useful insights for the sugar sector.

To ground this analysis, the study makes use of actual climate records, such as the average monthly heat indices in Negros Occidental, which were 32°C in November and 33°C in December 2022 (Silay, Philippines Weather History |

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Weather Underground, n.d.-b), while the average monthly heat index recorded in Negros Oriental in the same months was Negros Oriental 36°C and 33°C (Sibulan, Philippines Weather History | Weather Underground, n.d.). Moreover, during the first half of 2023, Negros Occidental registered monthly average heat indices of 34°C, 34°C, 35°C, 38°C, 38°C, and 37°C from January through June ((Silay, Philippines Weather History | Weather Underground, n.d.-c). In comparison, Negros Oriental recorded values of 33°C, 33°C, 33°C, 36°C, 36°C, and 36°C for the same months (Sibulan, Philippines Weather History | Weather Underground, n.d.-b).

For the closing months of 2023, the average monthly heat indices in Negros Occidental were 36°C in November and 35°C in December (Silay, Philippines Weather History | Weather Underground, n.d.-c). Meanwhile, Negros Oriental posted heat indices of 31°C and 32°C in these two months (Sibulan, Philippines Weather History | Weather Underground, n.d.-b). Furthermore, Weather records show that Negros Occidental experienced average monthly heat indices of 34°C, 34°C, 35°C, 39°C, 40°C, and 40°C between January and June 2024 (Silay, Philippines Weather History | Weather Underground, n.d.-d). In the same timeframe, Negros Oriental recorded corresponding values of 33°C, 34°C, 35°C, 38°C, 41°C, and 38°C (Sibulan, Philippines Weather History | Weather Underground, n.d.-c)

According to the Department of Agriculture (2023), statistics shows that the Philippines' sugarcane production has been decreasing annually, with reports estimating a drop of roughly 10% over the previous five years. It has been determined that a major contributing reason to this reduction, which affects crop quality and yield, is the high temperatures. The study identifies regional strengths and vulnerabilities by assessing the contributions of several provinces. This localized approach enables targeted interventions and resource allocation, ensuring that support is directed where it is needed most. Therefore, the researchers identified and compiled the average monthly heat indices (HI) recorded for each province over the relevant period. The researchers then collected data on the contribution percentages of each province to the total sugarcane production in the Philippines. This data should represent how much each province contributes to the overall output. For each province, check if the HI exceeds Tcons (25°C). If HI ≤ 25°C, note that there is no negative impact, and set RNI to 0. For provinces where HI > Tcons, apply the formula:
NPC = Cprovince × [WSI – [[[(HI - Tcons)/Tcons] × 100]/100]]
or
RNI = [(HI - Tcons)/Tcons] × 100
NPC = Cprovince × [WSI – (RNI/100)]

Where:
RNI = Rate of Negative Impact of heat index
NPC – New contribution of a province in the sugarcane industry
WSI – Whole Sugarcane Industry of the Philippines represented as 1
HI – Average monthly highest heat index recorded in the Province
Tcons – 25°C (the average temperature appropriate for sugarcane)
Cprovince – Percentage of the contribution of provinces

Conceptual Framework

The researchers will be able to calculate and contrast the heat index's percentage negative impact on sugarcane growth rate and how this affected the provinces' contributions to the industry's overall sugarcane production for November 2022 to June 2023 and November 2023 to June 2024 in Negros Occidental and Negros Oriental, using a mathematical formula they have developed. This study has gone through several stages to produce the desired outcomes, namely, A. input; B. procedure; and C. result.

The Input consists of the independent variable, dependent variable, and constant variable. For this study, the independent variable is the Heat Index (HIX), Rate of Negative Impact of heat index, Average monthly highest heat index recorded in the Province (HI), dependent variable being the New contribution of a province in the sugarcane industry (NPC), Rate of Negative Impact of heat index (RNI), and lastly the constant variable which is the mean temperature of the optimum temperature for sugarcane growth (2O°C - 30°C), Whole Sugarcane Industry of the Philippines represented as 1 (WSI) and Percentage of the contribution of provinces (Cprovince). This study uses a quantitative approach that involves mathematical computation.

The process of this study begins with the collection of data such as the heat index in Negros Occidental and Negros Oriental, the growth rate of sugarcane at a constant temperature, the percentage contributions of the provinces to the Sugarcane industry, and the constant temperature. The data is then processed and examined using the mathematical formula, NPC = Cprovince × [WSI – [[[(HI - Tcons)/Tcons] × 100]/100]]. The outcomes are then used to assess whether the heat index profoundly impacts sugarcane growth rate and the percentage contributions of the provinces to the Sugarcane industry

Results

The results derived from the formulated equation are summarized in the tables below. These tables contain the values of the variables used in the computation, namely heat indices, the rate of negative impact, and present the corresponding outcomes that describe the relationship between the heat index and production levels.

Table 1. NEGROS OCCIDENTAL (2022 – 2023)

MONTHS	AVERAGE MONTHLY HEAT INDEX	RATE OF NEGATIVE IMPACT	NEW CONTRIBUTION OF THE PROVINCE (from 60%)
NOVEMBER 2023	36°C	44%	33.6%
DECEMBER 2023	35°C	40%	36%
JANUARY 2024	34°C	36%	38.4%
FEBRUARY 2024	34°C	36%	38.4%
MARCH 2024	35°C	40%	36%
APRIL 2024	39°C	56%	26.4%
MAY 2024	40°C	60%	24%
JUNE 2024	40°C	60%	24%

Table 2. NEGROS ORIENTAL (2022 – 2023)

MONTHS	HEAT INDEX	RATE OF NEGATIVE IMPACT	NEW CONTRIBUTION OF THE PROVINCE (from 10%)
NOVEMBER 2022	36°C	44%	4%
DECEMBER 2022	33°C	32%	6.8%
JANUARY 2023	33°C	32%	6.8%
FEBRUARY 2023	33°C	32%	6.8%
MARCH 2023	33°C	32%	6.8%
APRIL 2023	36°C	44%	4%
MAY 2023	36°C	44%	4%
JUNE 2023	36°C	44%	4%

Table 3. NEGROS OCCIDENTAL (2023 – 2024)

MONTHS	HEAT INDEX	RATE OF NEGATIVE IMPACT	NEW CONTRIBUTION OF THE PROVINCE (from 60%)
NOVEMBER 2022	32°C	28%	43.2%
DECEMBER 2022	33°C	32%	40.08%
JANUARY 2023	34°C	36%	38.4%
FEBRUARY 2023	34°C	36%	38.4%
MARCH 2023	35°C	40%	36%
APRIL 2023	38°C	52%	28.8%
MAY 2023	38°C	52%	28.8%
JUNE 2023	37°C	48%	31.2%

Table 4. NEGROS ORIENTAL (2023 – 2024)

MONTHS	HEAT INDEX	RATE OF NEGATIVE IMPACT	NEW CONTRIBUTION OF THE PROVINCE (from 10%)

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NOVEMBER 2023	31°C	24%	7.6%
DECEMBER 2023	32°C	28%	7.2%
JANUARY 2024	33°C	32%	6.8%
FEBRUARY 2024	34°C	36%	6.4%
MARCH 2024	35°C	40%	6%
APRIL 2024	38°C	52%	4.8%
MAY 2024	41°C	64%	3.6%
JUNE 2024	38°C	52%	4.8%

Discussion

The formula for the rate of negative impact of heat index (RNI) calculates the extent to which increased temperatures above the optimal level for sugarcane growth affect productivity. This, in turn, determines how much a province's contribution to the overall sugarcane industry (NPC) declines, with higher heat indices resulting in larger reductions in the province's contribution due to the negative effects on sugarcane growth and yield. This study uses a quantitative approach that involves mathematical computation, expressed as NPC = Cprovince × [WSI – [[[(HI – Tcons)/Tcons] × 100]/100]], serving as a valuable tool for evaluating the influence of environmental factors, particularly heat index (HI), on the growth of sugarcane and its contributions from Negros Occidental and Negros Oriental to the Philippine sugarcane industry. By employing this formula, researchers can quantify the deviation between the prevailing heat index and the optimal temperature for sugarcane growth, represented by the constant temperature (Tcons) of 25°C.

High temperatures cause physiological impairments that significantly limit efficiency, especially during crucial growth stages such as development and ripening (Xue et al., 2025). Yield, as Fahad et al. (2017) explain, is the product of complex physiological processes, many of which are disrupted under heat stress. The degree of stress and the specific stage of plant growth determine the severity of yield reduction, highlighting the vulnerability of sugarcane to prolonged exposure to elevated temperatures.

Empirical studies reinforce these physiological findings. The heat stress index (HI) has been shown to exert a negative and statistically significant effect on sugarcane yield (Jagadish et al., 2007). Similarly, Aragón et al. (2021) documented a substantial drop in productivity under extreme heat exposure, consistent with the broader evidence that high temperatures compromise agricultural outputs. Despite its seemingly small coefficient, the HI has strong explanatory power when considered cumulatively, making it a critical variable for understanding climate impacts on crop productivity. This supports the use of mathematical tools such as the NPC formula in structuring the analysis of climate-agriculture interactions.

The application of the NPC formula underscores the importance of quantitative approaches in assessing the interplay between climate variability and crop performance. By mathematically expressing the deviation of prevailing heat indices from the constant optimal temperature, the formula provides a structured and evidence-based framework for evaluating provincial contributions to the industry under different climatic conditions. This not only strengthens the theoretical claims of climate-induced productivity loss but also has practical implications for policymakers and stakeholders. High-risk provinces with consistently elevated HI values can be identified, allowing the prioritization of adaptation measures such as optimized irrigation systems, adjusted planting calendars, and investment in heat-tolerant sugarcane varieties.

Nevertheless, as Xue et al. (2025) emphasize, further region-specific regression studies are needed to refine these findings. The impacts of heat stress are not uniform across all production regions, and adaptation strategies must be sensitive to local conditions. Developing climate-resilient crop varieties and implementing location-specific practices are essential to address the varied impacts of heat stress.

In general, the discussion highlights the direct and multifaceted influence of climate variability on sugarcane growth and yield. Elevated heat indices disrupt plant physiology, reduce productivity, and diminish the contributions of sugarcane-producing provinces to the national industry. By integrating the NPC formula with empirical evidence, this study establishes an objective and reliable method for analyzing climate impacts on agriculture. Ultimately, the findings reaffirm the urgency of adopting adaptive strategies and policies that not only mitigate the adverse effects of climate change but also ensure the resilience and sustainability of the Philippine sugarcane industry.

Conclusion

In conclusion, by using the formula NPC = Cprovince × [WSI – [[[(HI – Tcons)/Tcons] × 100]/100]] has been proven that the higher the heat index, the higher the negative impact on the sugar canes. This affects the livelihood of farmers and the well-being of communities that rely on this industry. As temperatures increase, crops may struggle to grow as they once did, leading to reduced harvests and fewer resources for the people and provinces that depend on them.

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