Cultivating a Greener Future: Unearthing Sustainable Farming Practices Amidst Climate Change and Pesticide Challenges

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Background

Pesticide Use and Environmental Impact

Pesticides have played a significant role in agricultural development, providing a means to control pests and diseases that can damage crops.1 However, their widespread use has also led to various environmental and health concerns. Pesticide contamination of soil, water, turf, and other vegetation has become a widespread problem, with groundwater pollution being particularly concerning.4 In developing countries, the use of pesticides has been linked to negative impacts on human health and food security.5

Sustainable Farming Practices

As the global community becomes more aware of the environmental and health risks associated with pesticide use, there is a growing interest in sustainable farming practices that can reduce dependence on these chemicals.3 Some developed countries, such as Denmark, France, Finland, and Japan, have already taken steps to reduce pesticide use intensity in recent years.2 These efforts highlight the potential for alternative approaches to boost crop yields without increasing pesticide use.

Climate Change and Pesticide Use

Climate change-related factors, such as temperature and rainfall, can also influence pesticide use and its adverse effects on the natural environment.1 As weather conditions become more unpredictable, it is crucial to understand how these factors interact with pesticide use and farm productivity. This understanding can help inform the development of more sustainable agricultural practices that are resilient to changing climate conditions.

A Roadmap for Sustainable Agriculture

In an era where food security and environmental health are intertwined, it is essential to find ways to reduce our dependence on pesticides and promote sustainable farming practices[^3^]. By studying countries that have successfully raised crop output while stabilizing or reducing pesticide use, we can uncover methods for better sustainable farming and provide insights that can be applied globally. Our future endeavor would be to create a roadmap for agricultural practices that nurture the land and its inhabitants while highlighting the value of sustainable farming in the context of food security and environmental health.

Research Questions

Question 1: How do weather conditions, like temperature and rainfall, influence farm productivity and pesticide use?

Understanding the role of climate factors in the link between farm productivity and pesticide use is crucial for developing sustainable agricultural practices that are resilient to changing weather conditions. This question seeks to explore the impact of temperature and rainfall on the effectiveness of various farming methods and their reliance on pesticides.

Question 2: Which countries have successfully raised crop output while stabilizing or reducing pesticide use?

This question aims to identify countries that have managed to boost their agricultural productivity without increasing their reliance on pesticides. By examining these nations, you can uncover the strategies and practices they have implemented to achieve sustainable farming.

Data Acquisition

To address the research questions, multiple datasets were sourced.

The rainfall and temperature datasets give a lengthy period of data for most countries in the world giving us average mm or rainfall per year and average temperatures in celsius. All four datasets were originally sourced from Kaggle where they were originally collected from the World Data Bank and the Food and Agriculture Organization of the United Nations. We used the datasets for rainfall and temperature data as noted below.

Rainfall Dataset (`rainfall.csv`):

- Location: Kaggle Crop Yield Prediction Dataset
- https://www.kaggle.com/datasets/patelris/crop-yield-prediction-dataset/data
- Format: CSV
- Important Variables: `Area`, `Year`, `average_rain_fall_mm_per_year`
- Number of Records: 6,727
- Time Period: 1985-2017

Temperature Dataset (`temp.csv`):

- Location: Kaggle Crop Yield Prediction Dataset
- https://www.kaggle.com/datasets/patelris/crop-yield-prediction-dataset/data
- Format: CSV
- Important Variables: `country`, `year`, `avg_temp`
- Number of Records: 71,311
- Time Period: 1743-2013

We were able to find the original source data from the Food and Agriculture Organization of the United Nations and sourced a download link to bulk download of data for all fields and dates available, these are noted below.

Pesticides Dataset (`pest.csv`):

- Location: Food and Agriculture Organization of the United Nations
- Data information page:https://www.fao.org/faostat/en/#data/RP
- https://fenixservices.fao.org/faostat/static/bulkdownloads/Inputs_Pesticides_Use_E_All_Data_(Normalized).zip
- Format: CSV
- Important Variables: `Country`, `Year`, `Pesticides`
- Number of Records: 112,350
- Time Period: 1990-2021

Yield Dataset (`yield.csv`):

- Location: Food and Agriculture Organization of the United Nations
- Data information page: https://www.fao.org/faostat/en/#data/QCL
- https://fenixservices.fao.org/faostat/static/bulkdownloads/Production_Crops_Livestock_E_All_Data_(Normalized).zip
- Format: CSV
- Important Variables: `Country`, `Year`, `Yield`
- Number of Records: 13,547
- Time Period: 1961-2021

Data Manipulation

Column Transformations and Data Cleaning

Upon initial review, the datasets exhibited inconsistencies in column naming conventions. For seamless data merging and processing, column names were standardized. Additionally, given the broad scope of some datasets (which included regions larger than countries such as continents, records specific to countries were filtered to maintain consistency across all datasets.

For the yield.csv dataset, which contained crop-specific data, yields were aggregated to provide a total yield per country per year. Only crop-specific rows (identified by code 5419) were considered, as the dataset also contained non-relevant data like livestock and crop processing.

Data Integrity Findings

Differences in country naming conventions were observed between the pesticides and yield datasets. For instance, while "Netherlands" was the term in the yield dataset, the pesticide dataset used "Netherlands (Kingdom of the)". Such inconsistencies were rectified to ensure proper data merging.

Both the rainfall and temperature datasets had missing data. A deep dive into these missing values revealed patterns. The temperature dataset, for instance, lacked data mostly from years before 1900. Given that our main analysis focused on more recent years, records prior to 1900 were discarded. For rainfall, the missing values were more evenly distributed across years. However, a few countries consistently lacked rainfall data. After evaluating the significance of these countries in the context of our analysis, it was decided to exclude them.

Data Type Rectification

The rainfall dataset contained non-numeric entries, which were converted to the correct numeric format for further analysis. Additionally, some values in the rainfall dataset were represented by "..". Given that rainfall data for each country remained consistent across years, these values were imputed using available data for the corresponding country.

Addressing Duplicates

Duplicate records were identified in the temperature dataset. Some countries, especially larger ones, had multiple temperature readings for the same year. This redundancy was attributed to readings from different geographical areas within those countries. To simplify the analysis, these readings were aggregated to provide an average temperature for the country for a given year.

Negative and Zero Value Rectification

Invalid negative values in the temperature dataset were replaced using a forward-fill strategy. Additionally, some countries reported pesticide use inconsistently, with usage reported for certain years and not others. Given the uncertainty around these figures, such inconsistent records were excluded from the analysis.

Trends and Correlations Analysis

The correlation data that we developed offers an understanding of the relationships that exist between various factors. The values we saw in this matrix range from -1 to 1. To break this down, a value which lands close to 1 demonstrates a substantial positive correlation, while a value nearing -1 indicates a significant negative correlation. By interpreting the matrix patterns, we've reached a few observations.

Specifically looking at the Yield variable, we note its positive correlation with Pesticides. This implies that as pesticide usage increases, the yield tends to increase as well. Contrary, a marginal negative correlation is observed with Temperature, which is interesting. This suggests that higher temperature might hinder crop yields to some extent. Lastly, the correlation between Yield and Rainfall is weak, implying that rainfall doesn't have a significant impact on yield.

A crucial point in the data is that the use of pesticides seems to boost crop yields, while standalone temperature or rainfall don't seem to have a defining correlation with yield. This perhaps hints at the presence of other factors that could be influencing crop yield. While our analysis is reductive and simplistic, we do recognize that myriad of other factors may be affecting crop yields such as soil quality, pest and plant disease pressure, seed quality and genetics, fertilizer use, irrigation and water use, pollinator presence and activity, just to name a few.

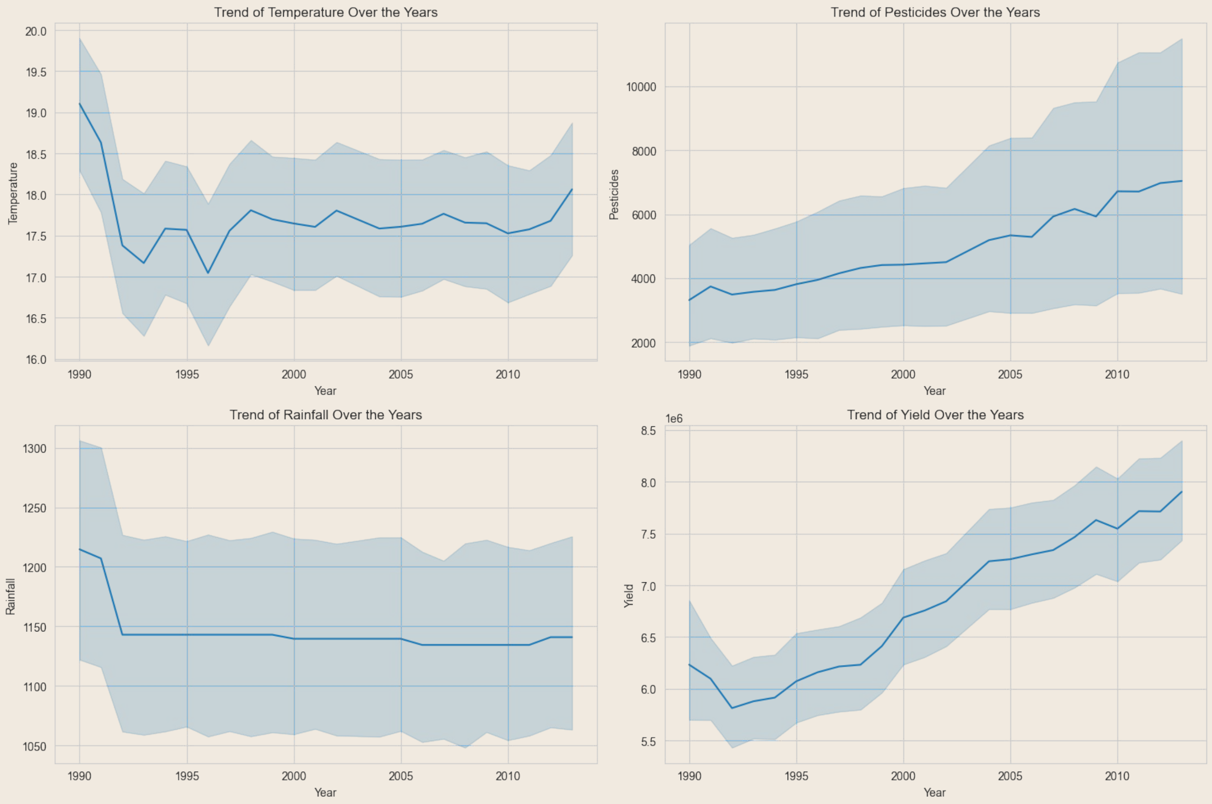


Figure 1. The graphs above show from top left to bottom, the trend of yield, pesticides, temperature and rainfall from 1990 to 2013.

Segment Analysis

Answer to Question 1

Our data segmentation revealed key interactions among temperature, rainfall, and pesticide use and their impacts on crop yields.

The "Low Temperature & Low Rainfall" segment yielded the highest average crop output, suggesting these crops thrive in cooler, drier conditions. In contrast, crops in the "High Temperature & High Rainfall" zone showed the lowest yields, indicating that excessive heat and rain might not be favorable for their growth. Interestingly, this cooler and drier segment also recorded the highest pesticide use, hinting at its potential role in boosting yields.

On the rainfall-pesticide interplay, the data showed that while high rainfall combined with pesticide use resulted in improved yields, regions with high rainfall but low pesticide use had lower yields. This suggests a synergistic effect of rainfall and pesticides in enhancing crop production.

In essence, understanding these interactions can guide better agricultural strategies. Particularly, regions with high rainfall but low pesticide use might offer insights into sustainable farming practices, minimizing pesticide dependence.

Furthermore, considering the environmental and health hazards linked to pesticide usage, areas experiencing high rainfall combined with heavy pesticide use is a concern. High rainfall can exacerbate the runoff of pesticides from fields, leading to contamination of the environment and groundwater sources[^4^]. This can also jeopardize human health and food security in developing countries[^5^]. Therefore, while high rainfall and pesticide use might boost crop yields short term, the potential long-term ecological and health damages might outweigh the benefits, underscoring the need for sustainable farming alternatives.

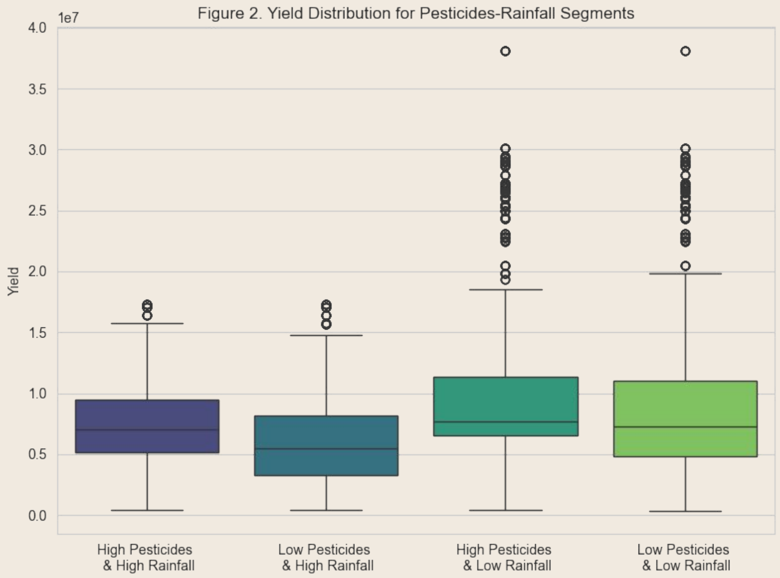


Figure 2. yield distribution based on pesticides and rainfall segments showing that

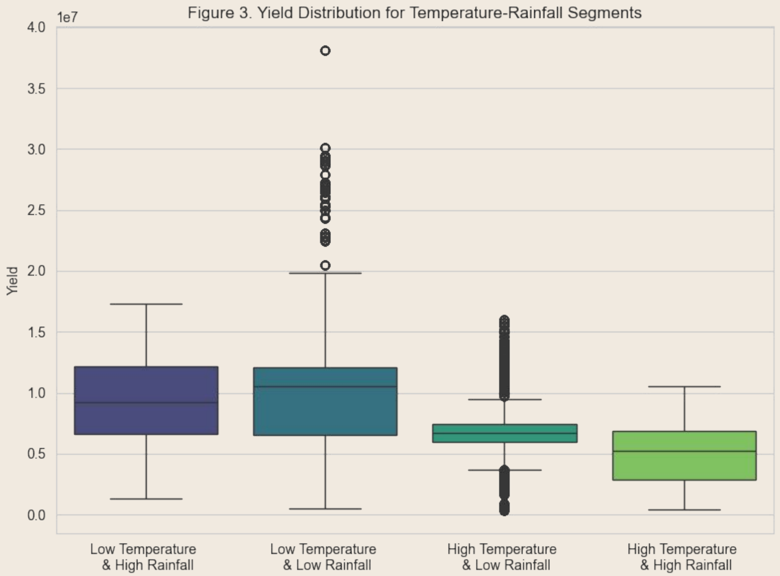


Figure 3. yield distribution based on temperature and rainfall segments showing that

Identifying Candidate Countries

Search for Sustainable Agriculture Practices

The heart of sustainable agriculture is to optimize crop yields without compromising environmental health. A pivotal indicator of this is the balance between crop yields and pesticide usage. Our approach involves analyzing countries that have managed to consistently reduce their pesticide usage while maintaining or even enhancing their crop yields. This was achieved by grouping the data by country and fitting two linear regression models for each: one highlighting the trend of crop yields (figure 4) and the other focusing on the trend in pesticide usage (figure 5). The slopes of these regression lines reveal the nature of these trends, with a positive slope in the yield model being desirable and a negative slope in the pesticide model indicating commendable reduction efforts.

Upon analyzing these trends, a list of countries showcasing a consistent reduction in pesticide usage and stable or increasing yields was identified. This list, served as a starting point for understanding and finding sustainable agriculture practices.

The alternative approach assesses sustainable agriculture by comparing the differences in yield and pesticide use between the initial and final years of data for each country. While this method simplifies the analysis and is computationally efficient, it might miss nuanced trends within the period. For example, a country could increase pesticide use initially and decrease it later, leading to a net reduction. This method contrasts with the initial linear regression approach, which offers a more comprehensive view of trends over time but is more computationally intensive.

Figure 4. Linear Regression of Yield vs. Year

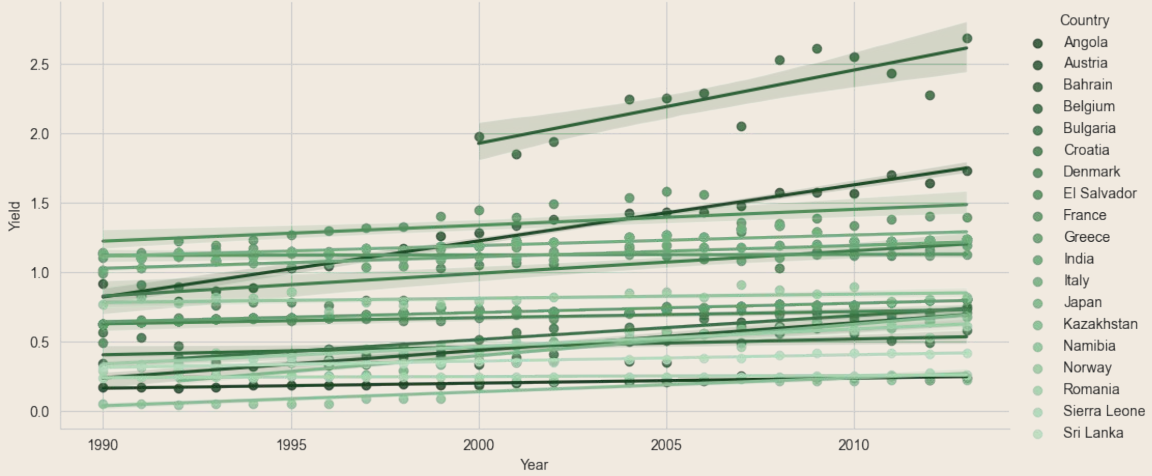
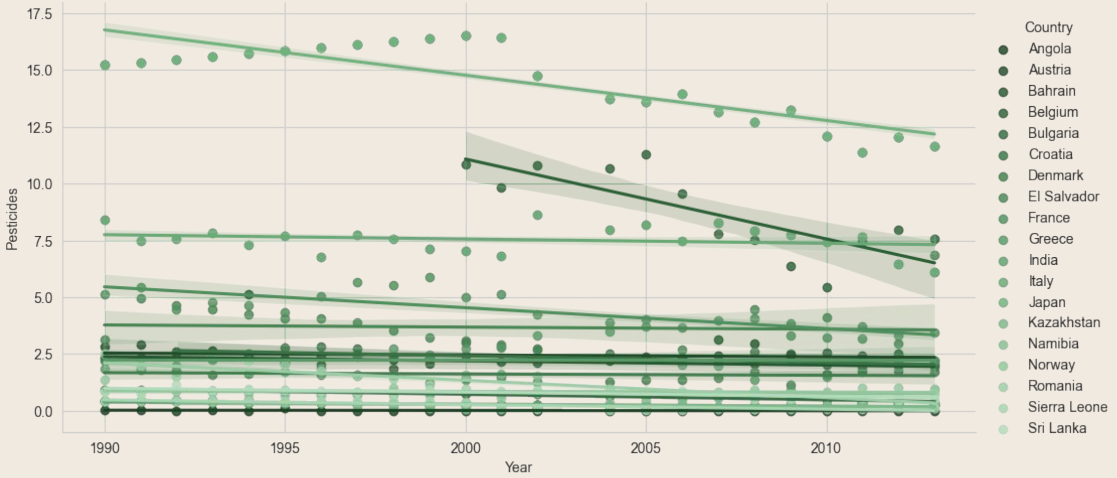


Figure 5. Linear Regression of Pesticides vs. Year



Ranking Candidate Countries

In our analysis, we ranked countries based on two metrics: the percentage increase in crop yield and the percentage decrease in pesticide use over a given period. This dual-faceted approach ensured that the countries listed not only excelled in agricultural productivity but also demonstrated sustainable farming practices.

Initially, we extracted the first and last recorded values for both yield and pesticide usage for each country. By calculating the percentage change between these two points, we were able to gauge the overall progression or regression of each country in these two areas. For crop yield, a positive percentage indicates growth, whereas for pesticide use, a negative percentage signals a reduction. To formulate a comprehensive ranking score, we combined these percentages: the percentage increase in yield was added to the percentage decrease in pesticide use. This aggregate score served as a marker of a country's productivity and sustainability. Subsequently, we organized the countries in descending order based on this combined score, ensuring that nations at the top of our list demonstrated the most significant improvements in both metrics.

By employing this method, we have curated a list of countries that have successfully balanced the scales of agricultural output and environmental responsibility.

	Country	Yield Percentage Increase	Pesticide Percentage Decrease	Ranking Score
0	Romania	110.220283	69.841270	180.061553
1	Kazakhstan	135.699430	38.775510	174.474940
2	Bahrain	116.098309	12.820513	128.918822
3	Thailand	61.780656	59.340659	121.121315
4	Austria	88.566285	22.340426	110.906711
5	Angola	40.400628	50.000000	90.400628
6	Hungary	59.956991	28.215768	88.172759
7	Sierra Leone	10.975799	71.428571	82.404371
8	Zimbabwe	4.773443	67.368421	72.141864
9	Sri Lanka	35.115039	34.939759	70.054798
10	Bulgaria	2.299790	64.893617	67.193407
11	Sweden	42.842739	23.456790	66.299529
12	India	27.629236	38.636364	66.265599
13	Belgium	35.743873	30.193906	65.937779
14	France	26.642640	32.879377	59.522017
15	Libya	16.737984	39.669421	56.407405
16	Italy	18.078009	27.142857	45.220866
17	Egypt	16.528353	26.653307	43.181660
18	Norway	5.882543	31.386861	37.269405
19	Japan	8.786725	23.587385	32.374110
20	Denmark	6.896848	21.363636	28.260484

Trends for Candidates

Over the years, there has been a discernible shift in agricultural patterns. Notably, crop yields have demonstrated a consistent upward trajectory, signaling advancements and improvements in production methodologies. This positive trend in yields suggests that farming practices have evolved to become more efficient, harnessing innovative techniques to enhance crop yield.

Conversely, the utilization of pesticides presents a different narrative. While there have been periodic fluctuations, a general trend indicates an increase in their use over time, as depicted in Figure 6. This could be attributed to various factors, including the need to combat increasing pest resistance or maintain crop yields. In parallel, the average temperature has been gradually climbing, as shown in Figure 7. Rainfall, on the other hand, has witnessed intermittent variations without establishing a definitive trend in either direction. Given these observations, these factors satisfy questions, marking them as important areas for further exploration.

Figure 6. Pesticide Use Trends Over the Years

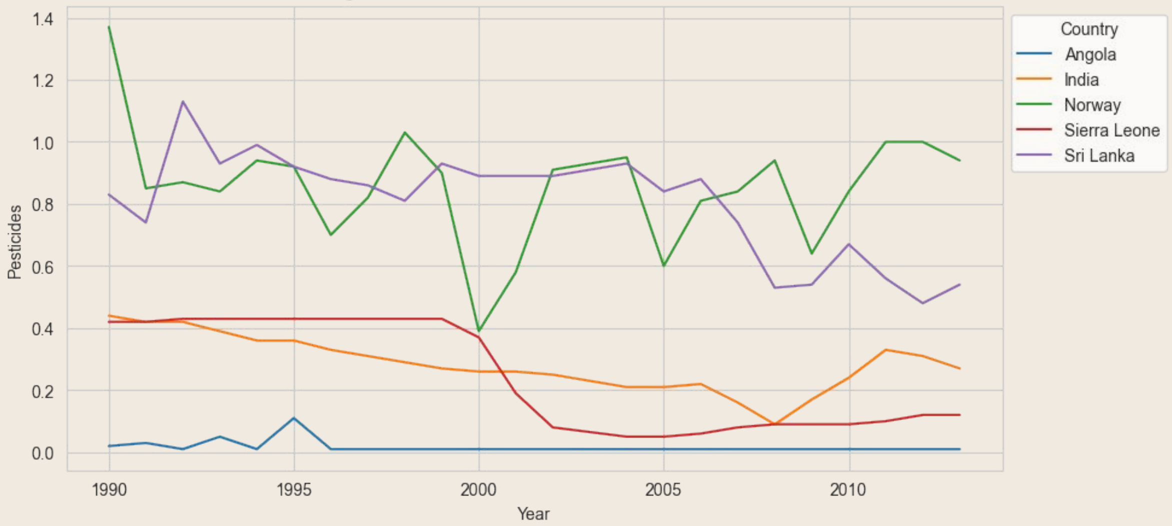
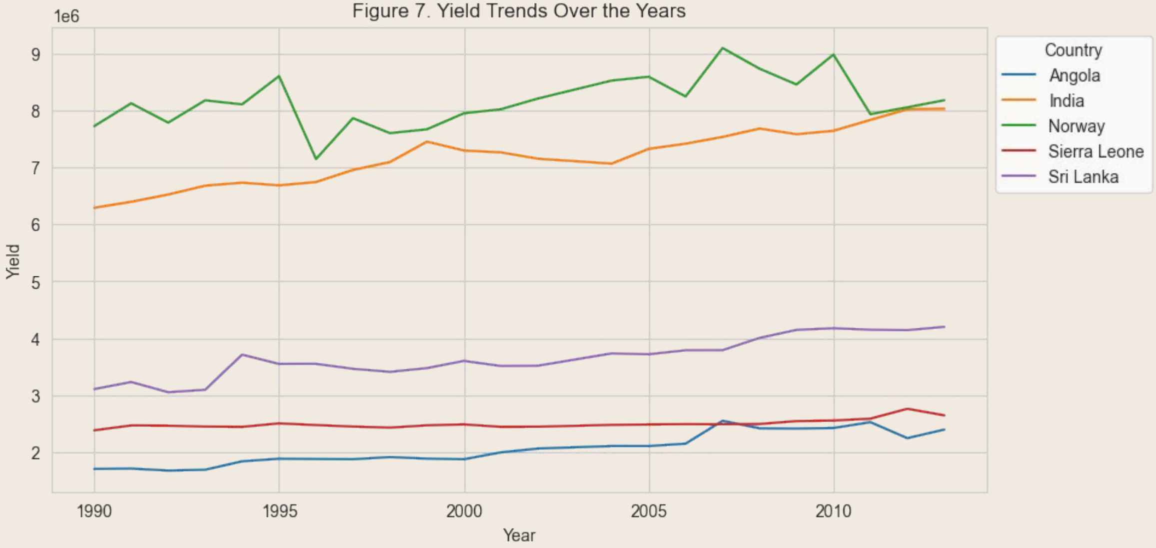


Figure 7. Yield Trends Over the Years



Candidates Countries

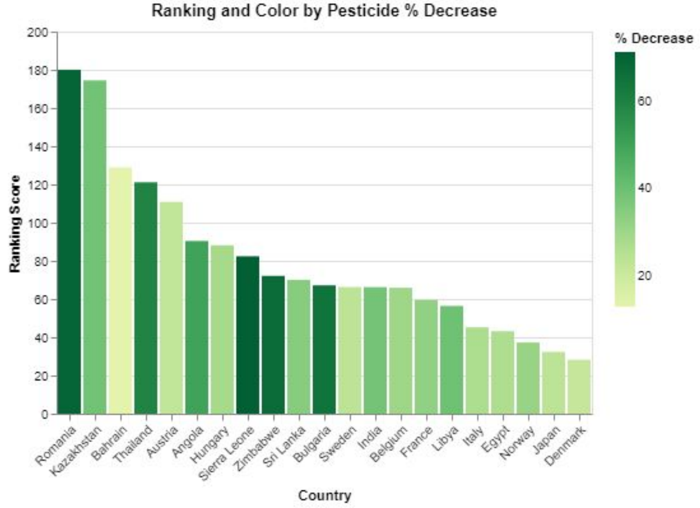
Answer to Question 2:

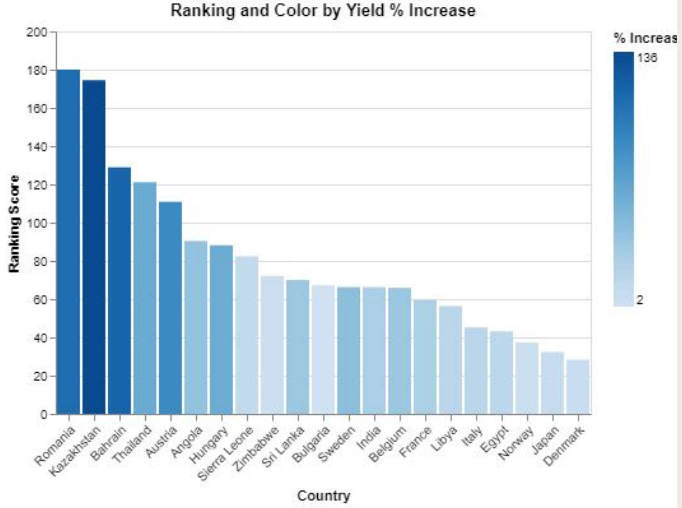
Our analysis has presented some intriguing findings regarding the rankings of various countries in terms of sustainable farming practices. Notably, Sierra Leone, Sri Lanka, India, and Norway display similarities in their rankings. The inclusion of both Sierra Leone and Sri Lanka, which are relatively smaller nations, alongside larger countries like India and Norway, offers a diverse perspective. This diversity is crucial for a more comprehensive understanding, given the inherent differences in agricultural practices, economies, and challenges faced by countries of varying sizes.

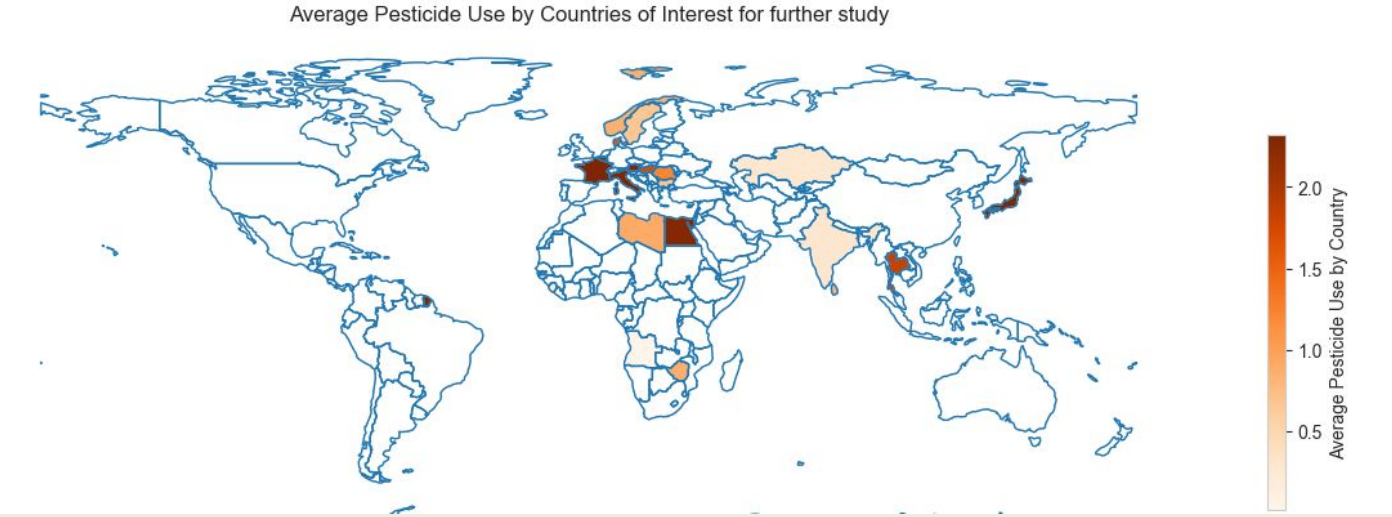
It's particularly noteworthy to witness India's ranking in this context. Given its vast expanse, diverse agro-climatic conditions, and the significant role agriculture plays in its economy, the ranking provides food for thought. The presence of India in this list underscores the importance of analyzing large nations with extensive agricultural landscapes.

For future studies aimed at delving deeper into sustainable farming practices, I suggest commencing with the aforementioned four countries. Their varied sizes and challenges would provide a rich tapestry of insights, enabling useful comparisons and potentially revealing actionable solutions that can be implemented on a global scale.

Furthermore, our trend list offers an exhaustive roster of countries that are making strides in sustainable farming. This list, which includes nations from Romania to Denmark, provides a roadmap for researchers and policymakers. Each country on this list represents unique agricultural practices, challenges, and successes. Studying these nations will not only shed light on the diverse ways in which sustainability is approached in agriculture but also inspire innovative solutions that can be adapted and adopted worldwide.







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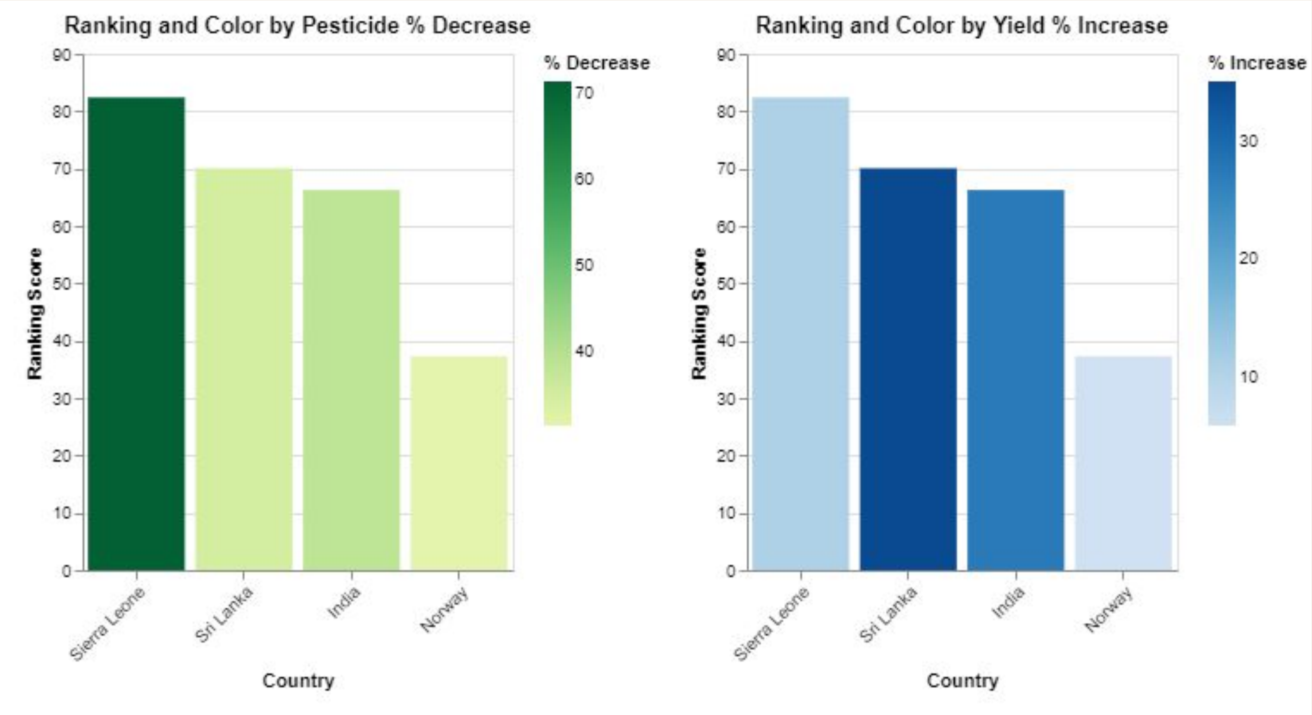
Exemplar Countries for Further Study:

Sierra Leone, Sri Lanka, India, Norway, Romania, Kazakhstan, Bahrain, Thailand, Austria, Angola, Hungary, Zimbabwe, Bulgaria, Sweden, Belgium, France, Libya, Italy, Egypt, Japan, Denmark.



Statement of Work and References

Statement of work

Osamudiamen IGBINIDUN.

Osas assisted in framing the project topic which was modified by Nick before submission and approval and acquisitions of original datasets. Also, data gathering, cleaning, merging, correlation analysis and discussion in the report some parts of visualizations was done by Osas. He is the primary author of the 'temporal_merged_data.csv. He was actively involved in debugging including codes and editing report content.

Nicholas Abram

Nick led in gathering of more data in addition to the original datasets and also, in data reduction which includes cleaning of dataset. Nick is the primary author of merged_df.csv file.He also analyzed correlations among variables. The collaborative environment for this project was set-up by Nick. He is the primary author of a github repository called um-milestone which was used for this milestone. Also, final codes compilations and also final reports was done by Nick. He was actively involved in debugging codes and editing all report content.

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