Growth on Paper, Loss on the Ground: Crops, Global Warming, and Farmer Incomes

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1. Introduction

Crop production today is at an all time high, farming and farmers are thriving and we have more surplus food today than we ever have in the history of humankind. At first glance, yields are going up worldwide. This is reassuring; despite climate change, despite rising global temperatures, we are thriving. Simple numbers are enough to confirm this fact plainly. But once we peak beneath the curtains facts start getting blurry and individual factors such as rising costs, lack of income from crops, environmental strain, start showing us the reality. So, is farming actually as profitable, fruitful and thriving as it appears?

This report studies the tale numbers tell v/s. the story statistical inference tells. We will look into the case of India where despite crop production going up in absolute terms, farmers are actually earning less from it. Using temperature, yield and income data, it can be seen how rising input costs, climate stress and the need for adaptation to climate change are eroding at the profitability of farming even if numbers look good on paper and attempt to answer the question:

> If wheat or crop yield is rising, why are farmers in India still struggling? Does climate change play a role?

This a story about how numbers and charts, without understanding and insight, don't always speak the truth.

The report is divided into 2 parts. Part A studies the effect of Climate upon Yield and tries to uncover the hidden cost of high yield under climate stress. Part B tries to fully answer our research question and studies how farmers' livelihood is actually affected due to global warming and how high crop yields come at a huge cost, not only to farmers but the Earth. Both parts are concluded in Conclusion followed by an Appendix and References.

Note:The submission has 2 RMD files:

1. CW_KCDAR_M Amisha Das C00313459 Report(WITHOUT FLEX).rmd (this report, without flex dashboard layout)
2. CW_KCDAR_M Amisha Das C00313459 Report(FLEX DASHBOARD).rmd (contains the flex dashboard layout)

2. Part A Correlatoin Between Climate & Wheat Yield

A.1. About Climate & Wheat Yield

To study global crop yield and the effects of climate upon it, wheat is chosen as the primary crop as subject of study.

Wheat is one of the world's most important staple crops. Grown worldwide, it is accessible to grow but it is also sensitive to heat stress. This makes wheat the best candidate for studying the effects of global warming upon crop production.

Is there actually a problem?

Before we explore the data we should keep the question in mind: should we even be worried? Let us explore data to answer this question.

A.2. Data Analysis

A.2.1. About Data

We use two datasets:
- **Global Temperature Anomalies**: monthly average anomalies from Berkeley Earth (Berkeley Earth, 2024).
- **World Wheat Yield**: FAO-based yearly wheat yield in tonnes/hectare (Food and Agriculture Organization of the United Nations, 2023).

Through this analysis, we aim to explore the relationship between rising global temperatures and wheat productivity over time.

A.2.2. Data Cleaning and Preparation

Preview of Temperature Anomaly Data

Year	Month	Monthly	Annual
1850	6	-0.332	-0.436
1851	6	-0.240	-0.321
1852	6	-0.099	-0.292
1853	6	-0.160	-0.295
1854	6	-0.456	-0.283
1855	6	-0.324	-0.278

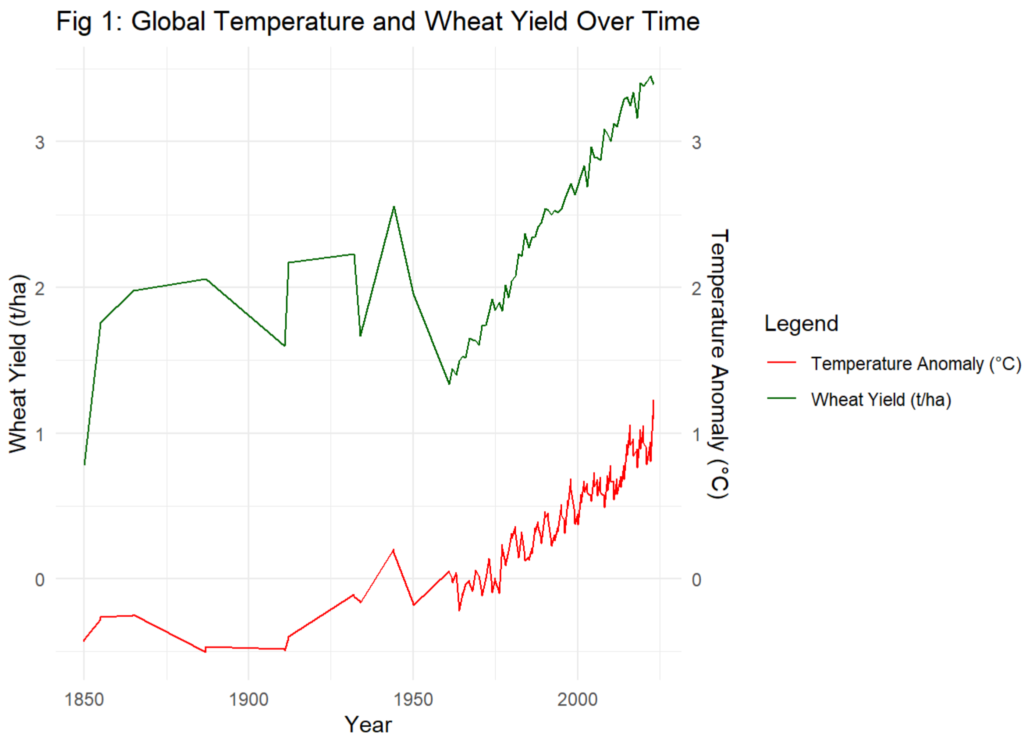
Note: Temperature values in this dataset are reported as anomalies, which represent the difference between the recorded global average temperature and the baseline average from 1951 to 1980.Positive anomalies mean warmer-than-average conditions. Negative anomalies mean cooler-than-average conditions. This standardisation helps compare long-term temperatures across different regions and time periods.

Preview of Global Wheat Yield Data

Entity	Year	Yield
Afghanistan	1961	1.0220001
Afghanistan	1962	0.9735001
Afghanistan	1963	0.8317000
Afghanistan	1964	0.9510000
Afghanistan	1965	0.9723000
Afghanistan	1966	0.8666000

Note: Wheat yield is measured in tonnes per hectare (t/ha) under the column 'Yield', indicating how much wheat is harvested per unit of cultivated land. It serves as a key indicator of agricultural productivity. Higher yields suggest better farming efficiency, whereas declining yields can signal issues such as climate stress, soil degradation, or lack of technological access. We have used the median month i.e June (annual centre) value to assume as yearly yield value. Berkeley Earth also uses June as the anchor value in their dataset.

A.3. Visualising Global Temperature Rise and Wheat Yield



A.3.1. Observations

As wheat yield shows improvement with time we can easily take this as a positive sign.

Going back to our initial question: is there a problem? At first glance, no. It looks as if, even with rise in temperature, wheat yields are in fact growing. Good news, right? If we stopped here, we can easily conclude that global warming is in fact not a problem, that we are not only making do, we are thriving. But as we will see, that this isn't the reality. Which is why statistical inference in necessary.

However, this is increase in yield by time alone. To see the explicit effects of temperature upon the yield, we run a regression to study the effect climate separately.

Part A.4. Regression Analysis

While regression is commonly used for forecasting, in this analysis it serves an explanatory purpose. Our goal is to determine whether rising global temperatures have an independent effect on wheat yield, beyond improvements over time due to agricultural technology. By comparing a model that includes only **Year** to one that includes both **Year** and **mean_temp**, we isolate the influence of climate.

```
# Model 1: Yield ~ Year (captures trend over time)
model_year <- lm(Yield ~ Year, data = climate_yield)

# Model 2: Yield ~ Year + Temperature (tests temperature's additional effect)
model_temp <- lm(Yield ~ Year + mean_temp, data = climate_yield)

# Compare model fits (R²). We are testing to see if the coefficient is significant enough
summary(model_year)$r.squared   # R² without temperature
```

```
## [1] 0.5275205
```

```
summary(model_temp)$r.squared   # R² with temperature
```

```
## [1] 0.7993386
```

The increase in R^2 from **0.53 to ~0.80**, along with the negative coefficient for temperature, is strong evidence that global warming is suppressing wheat yield growth — even is the overall yields are rising.

Explanation

To explain how this is actually working, let us assume the following is what yield is affected by:

1. Year (tech, policies, fertilisers, irrigation improvements)
2. Temperature (heat stress, drought, shortened grain-filling)

But we know that time and temperature are correlated — both are increasing anyway.

So we ask: **"How do we know which one is actually influencing yield?"**

For

1. *lm(Yield ~ Year)*

We are asking: **"How much of the change in yield can be explained by time alone?"** This captures everything that changes over time, not just tech — it includes climate too.

But with the second model:

2. *lm(Yield ~ Year + mean_temp)*

We're asking: **"If we already account for time, can we see that temperature still show effects for any leftover variation in yield?"**

As the coefficient for mean_temp is significant and R^2 has increased. Hence, the answer is yes. That means temperature adds independent information to our data. After adjusting for the fact that yield would go up with time anyway, warming is still pulling it down. Comparing it to a model with only year, we see that the time trend is not enough. This shows that temperature has a unique, measurable, and negative effect on yield.

Demonstration

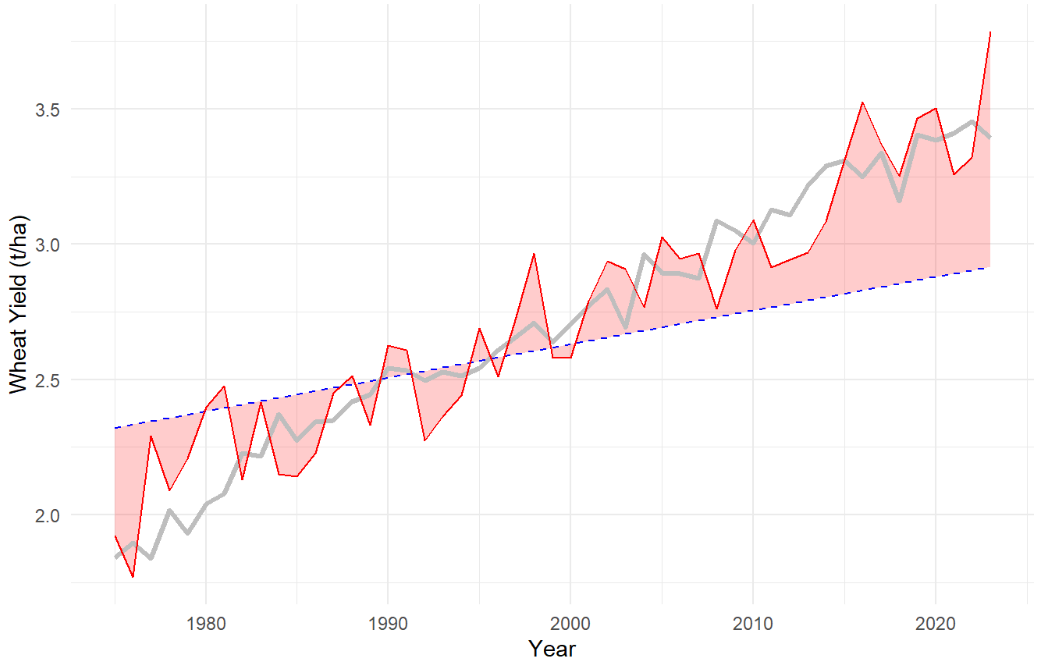
Interpretation

This plot represents the actual wheat yield over time from the beginning of the report (grey line) against our two regression models: 1. **Blue dashed-line:** model with only year (time) to predict yield 2. **Red lines and shades:** model with year and Temperature to predict loss of yield. Every red area is how much yield was lost from the predicted (blue) and original yield (grey)

```
ggplot(climate_yield_filtered, aes(x = Year)) +
  geom_ribbon(aes(ymin = pred_temp, ymax = pred_year), fill = "red", alpha = 0.2) +
  geom_line(aes(y = Yield), color = "grey", linewidth = 1.2) +
  geom_line(aes(y = pred_year), color = "blue", linetype = "dashed") +
  geom_line(aes(y = pred_temp), color = "red") +
  labs(
    title = "Fig 2: Estimated Climate Penalty on Wheat Yield (1975–2025)",
    subtitle = "Red area shows yield loss due to rising temperatures",
    y = "Wheat Yield (t/ha)", x = "Year"
  ) +
  theme_minimal()
```

Fig 2: Estimated Climate Penalty on Wheat Yield (1975–2025)

Red area shows yield loss due to rising temperatures

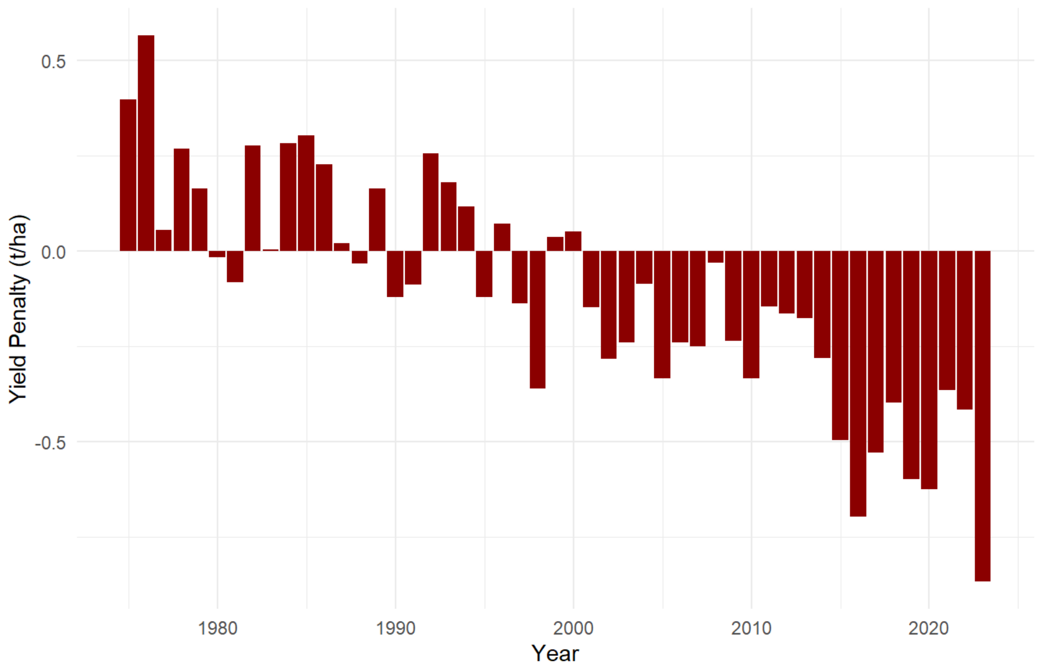


The shaded area is the amount of wheat yield lost.

This can be better visualised by the following chart:

Fig 3: Estimated Climate Penalty by Year

Difference in predicted yield due to temperature



In the above bar chart we can see more instinctively the estimated loss of wheat yield (t/ha) attributed to the temperature rise each year calculated by our *climate_penalty* calculated visa regression.

Part A Conclusion

Through our regression models and the subsequent visualisations it is clear that temperature is having a suppressing effect on yield. Our production is being held back from its full potential. **Note:** Regression does not show causation but only correlation. Therefore, there is a strong negative correlation in recent years from temperatures (when global warming has become worse) than it was earlier and we are losing yield because of it.

The regression model allows us to quantify how global temperature anomalies impact wheat yield all around the world, including India. A negative climate penalty (check Appendix 1 for complete table) indicates that yield declines with rising temperatures. We're not failing, but we aren't thriving either.

So, how is crop yield rising if global temperatures are also rising? Shouldn't it fall, as our regression model suggests? The answer is: **it is rising at the cost of farmers.**

2. Part B: Farmer Income Trends – Economic Impact

B.1. Wheat Production Analysis

B.1.1. About Production Data

We use FAO's "Value of Agricultural Production" dataset as before however this time for production value. Data is filtered for: - **Item = Wheat** - **Area = India** - **Element = Gross Production Value (constant 2014-2016 thousand Int$)**

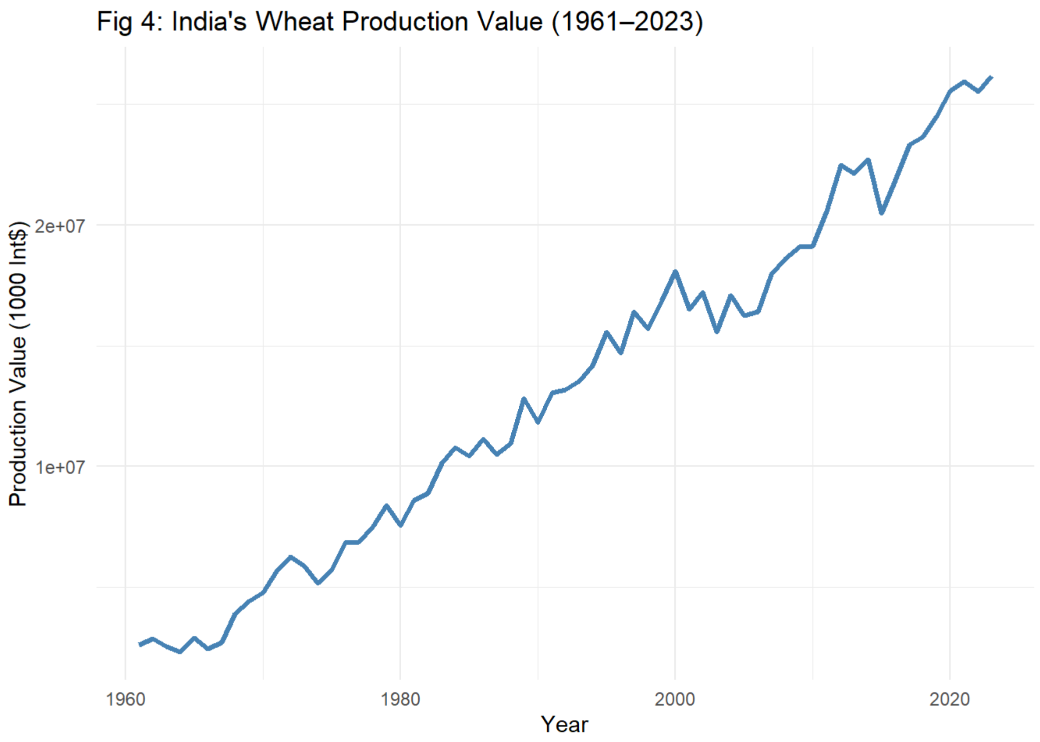
B.1.2. Production Data Cleaning and Filtering

```
# Check if data loaded properly
kable(head(wheat_val_long), caption = "Preview of Wheat Production Data")
```

Preview of Wheat Production Data

Item	Year	Value
Wheat	1961	2604428
Wheat	1962	2859021
Wheat	1963	2552088
Wheat	1964	2333493
Wheat	1965	2902834
Wheat	1966	2461619

The above data shows wheat production value where 'Year' is the year of production, and the production value is in 'Value' column represented in $(International Dollars), adjusted for inflation constant of 2014-2016.



It looks good right?

We previously saw that practically wheat yield is going up accoridng to FAO data, and so are farmer's earnings! So what is the problem? Earnings from actual farming and crop production has reduced. Not only that but global warming has led to farmers employing extra farming methods such as technology, extra irrigation, etc. which has actually increased cost of production and reduced the earnings farmers make. > Production ≠ Profit
Higher crop yield and increased earning does NOT equal profitable farming! This why our analyses are useful.

How is this affecting farmers?

So, we reach the crux of the problem. How global warming isn't affecting just wheat yield but how it is affecting people. In this case, the farmers who bring us our food (**pulitzer2022farmersclimate?**).

Data from the Situation Assessment Surveys (Kunal Munjal, 2022) shows that real income from farming and crop activity has actually declined in recent decades. This has been cited to increasing costs and the increase in global temperatures which has led for farmers to depend on irrigation, extreme weather losses and pest stress. The reality is that farmers are producing more and earning less.

Increased Irrigation Efforts Amid Climate Challenges

One such example is of how increased irrigation efforts have led to groundwater depletion all over India (Rohilla et al., 2024) and it is predicted that the depletion rates could triple in the coming decades (Michigan News, 2024). Rohilla et al. found that under current circumstances continued global warming might triple ground-water depletion. This is troublesome as 60% of India already depends on ground water and if this continues farmers will most likely lose the ability to irrigate with groundwater altogether.

B.2. Farmer Income Analyses

B.2.1. About Income Data

We use 2 data sets from SAS as mentioned by Munjal in their report (Kunal Munjal, 2022)
1. Income classified by Land Size owned by a person, which is categorised into various occupations
2. Income classified by the state resided in by a person. This is used to calculate total earnings later on but is similar in format to income classified by land owned.

Two similar but varying datasets are used for varacity, to see if the same conclusions can be drawn from both datasets despite being classified differently.

Preview of Income by Land Size

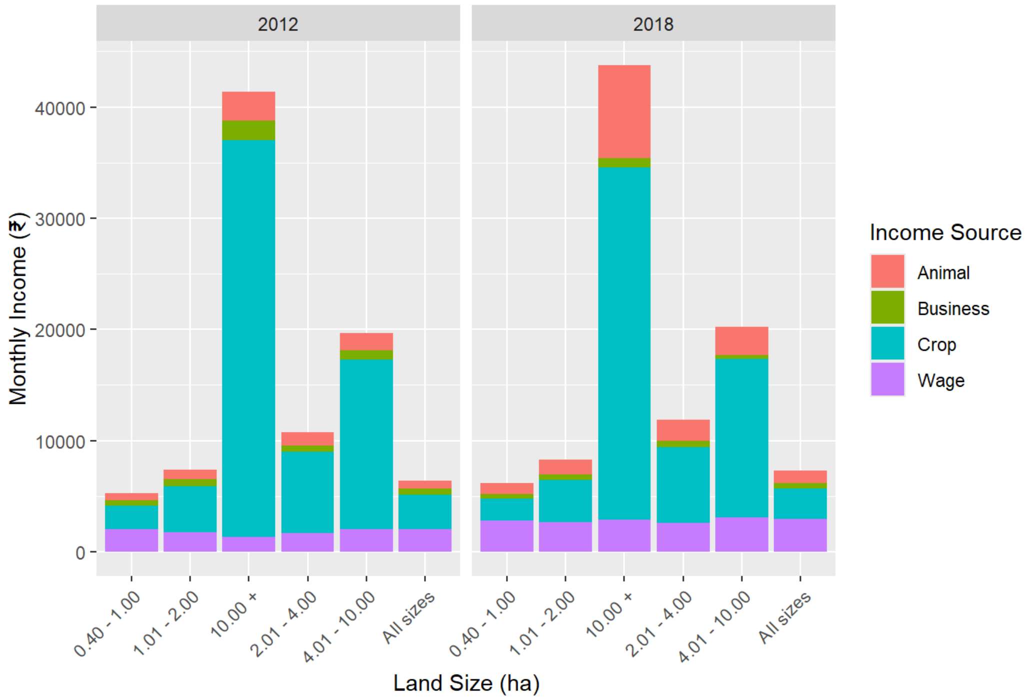
Size_class_ha	Wage_2012	Wage_2018	Crop_2012	Crop_2018	Animal_2012	Animal_2018	Business_2012	Business_2018	Total_2012	To
0.40 - 1.00	2011	2839	2145	1950	629	970	462	414	5247	
1.01 - 2.00	1728	2651	4209	3830	818	1341	592	446	7348	
2.01 - 4.00	1657	2579	7359	6855	1161	1854	554	551	10730	
4.01 - 10.00	2031	3106	15243	14278	1501	2508	861	343	19637	

Size_class_ha	Wage_2012	Wage_2018	Crop_2012	Crop_2018	Animal_2012	Animal_2018	Business_2012	Business_2018	Total_2012	To
10.00 +	1311	2869	35685	31689	2622	8339	1770	845	41388	
All sizes	2071	2953	3081	2760	763	1150	512	466	6426	

Above table shows data from Situation Assessment Survey (SAS) from the years 2012-13 and 2018-2019. Columns are marked in the format *'Occupation_Year'*. For example, 'Crop_2018' is the earning in indian rupee (INR) from Crop farming in the year 2018. "Size_class_ha" column is area of land owned in hectares.

B.2.2. Visualising Income of Farmers

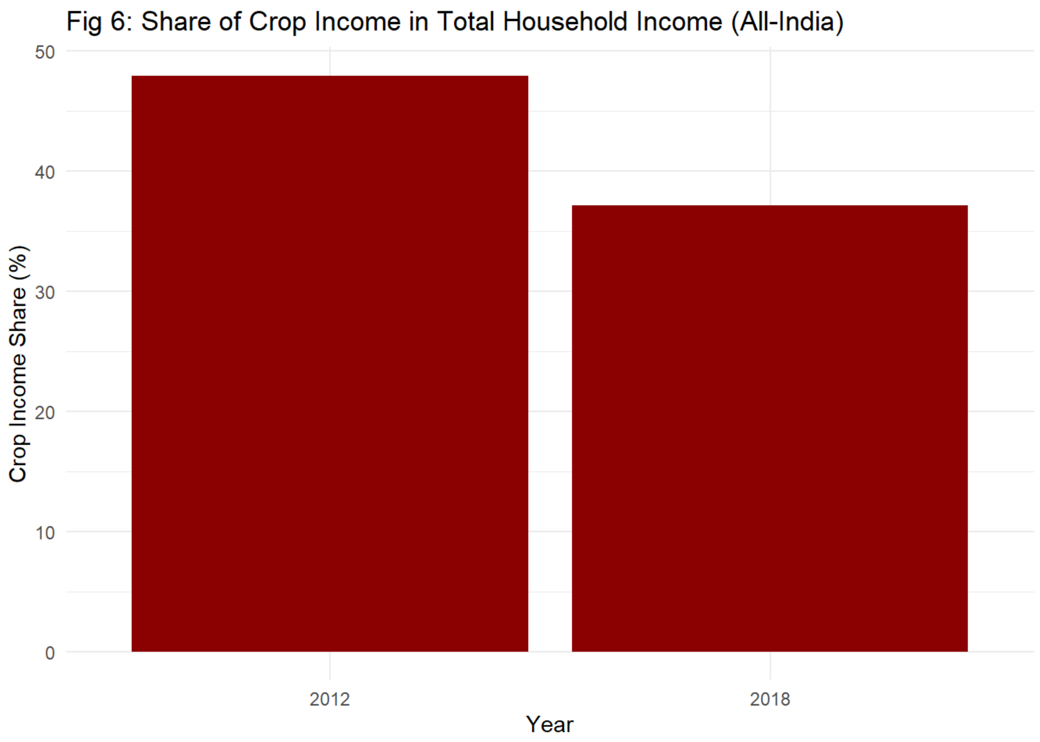
Fig 5: Income Composition by Land Size (2012 vs 2018)



We can observe the following changes from 2012-2018:

1. Crop income dropped by 9.4%, from ₹11,287 to ₹10,227
2. Animal income more than doubled, rising by 116%
3. Wage income rose by 57%
4. Business income dropped sharply by 35%

The drop in crop earning can be observed from our second data set as well, as illustrated below:



Part B Conclusion

We can see that despite wheat productivity (money earned from wheat production) has increased, the earning made by farmers from farming has decreased which can be seen through the earning difference from 2012 vs 2018. This is a plain sign of how a farmer's earnings and livelihoods have been affected by global warming and increased input into producing high yield of crops.

4. Conclusion

Our analyses have shown that climate change is exerting a very obvious and negative effect on agricultural productivity. Farmer's livelihoods are also being affected in the process and perhaps all over the world. The regression analyses we started with (climate time-series data and wheat-yield time series data) calculated a climate_penalty which showed us how much wheat we could have been producing but we have not been. This sowed us the hidden costs and stakes that aren't visible in plain data without statistical inference. It hides over-irrigation, technology input and the struggles of farmers sometimes at a personal cost.

From the SAS survey data we saw that cultivation income has dropped between 2012 and 2018. Farmers earnings from crop cultivation, ironically, is less while they earn more from non-farming endeavors such as animal husbandry. The farming income dropped from 48% in 2012 to 37% in 2018 while animal husbandry income increased by 113%. While total income seems to tell the story that farmers are doing better, it is not from farming that they get this increase in income. So, farmers are earning more but they are also investing more as we saw by the increase in groundwater irrigation.

The picture is clear: farmers are growing more, but earning less from what they grow. This is a symptom of a potential burnout. Climate change hasn't stopped wheat production — but it has made farming more costly, less profitable, and more fragile and rising global temperatures are holding us back from what we could be producing.

Future Work

In the future, I would like to analyse more Worldwide data such as struggles of farmers in different parts of the world. I would also like to analyse other crops than wheat, for example rice or maize which are produced in high quantity than wheat. Investigation more into other methods being employed to combat global warming other than over irrigation such as technology or cattle-rearing.Further analysis would also benefit from time-series income data to use a second regression model that can analyse the relationship between yield and farmer earnings. In this case, microdata from the NSS 77th Round was accessed but its format and language complexity made direct extraction very difficult and time consuming, therefore I would definitely like to use it with more time in future research.

Appendix 1

Relating to our regression model, we can see the climate penalty for the past 50 years generated via our regression model in the table below:

Estimated Climate Penalty on Wheat Yield (1975–2025)

Year	Actual_Yield	Predicted_Yield_Year_Only	Predicted_Yield_Year_Temp	Climate_Penalty
1975	1.843	2.321	1.923	0.398

Year	Actual_Yield	Predicted_Yield_Year_Only	Predicted_Yield_Year_Temp	Climate_Penalty
1976	1.897	2.333	1.768	0.565
1977	1.839	2.346	2.291	0.055
1978	2.018	2.358	2.091	0.268
1979	1.930	2.371	2.207	0.164
1980	2.042	2.383	2.399	-0.016
1981	2.079	2.395	2.476	-0.081
1982	2.228	2.408	2.131	0.277
1983	2.215	2.420	2.416	0.005
1984	2.372	2.433	2.150	0.283
1985	2.274	2.445	2.142	0.303
1986	2.343	2.458	2.229	0.229
1987	2.348	2.470	2.450	0.020
1988	2.419	2.482	2.515	-0.032
1989	2.445	2.495	2.332	0.163
1990	2.542	2.507	2.627	-0.120
1991	2.532	2.520	2.608	-0.088
1992	2.497	2.532	2.275	0.257
1993	2.528	2.544	2.364	0.180
1994	2.514	2.557	2.440	0.116
1995	2.542	2.569	2.690	-0.121
1996	2.608	2.582	2.510	0.072
1997	2.659	2.594	2.731	-0.137
1998	2.711	2.606	2.967	-0.361
1999	2.639	2.619	2.581	0.038
2000	2.705	2.631	2.579	0.052
2001	2.774	2.644	2.790	-0.147
2002	2.835	2.656	2.938	-0.282
2003	2.691	2.668	2.908	-0.239
2004	2.963	2.681	2.767	-0.087
2005	2.893	2.693	3.026	-0.333
2006	2.892	2.706	2.945	-0.239
2007	2.874	2.718	2.967	-0.249
2008	3.087	2.730	2.762	-0.031
2009	3.050	2.743	2.978	-0.235
2010	3.003	2.755	3.089	-0.334
2011	3.128	2.768	2.914	-0.146
2012	3.107	2.780	2.944	-0.164
2013	3.216	2.792	2.969	-0.177
2014	3.290	2.805	3.085	-0.280
2015	3.309	2.817	3.312	-0.495
2016	3.248	2.830	3.527	-0.697

Year	Actual_Yield	Predicted_Yield_Year_Only	Predicted_Yield_Year_Temp	Climate_Penalty
2017	3.339	2.842	3.370	-0.528
2018	3.161	2.855	3.251	-0.397
2019	3.405	2.867	3.465	-0.599
2020	3.383	2.879	3.503	-0.624
2021	3.409	2.892	3.257	-0.365
2022	3.455	2.904	3.320	-0.416
2023	3.392	2.917	3.784	-0.868

In the above table, we can see how much yield we ‘missed out on (tonnes per hectare)’ due to global warming. In 2023, despite technological gains, 0.868 tonnes per hectare of potential wheat yield was lost due to climate stress. The effect is marginally greater in recent year therefore, global warming is halting the yield of wheat

References

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