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Article

Impact of temperature and precipitation on *Solanum tuberosum* cultivation using climate scenarios to 2100

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Abstract: The objective was to estimate the monetary loss of potato producers up to the year 2100 as a result of temperature and precipitation impacts, taking into account the A2 and B2 scenarios of the IPCC (Intergovernmental Panel on Climate Change). The Pooled Production Panel Model was used, whose database was prepared taking into account climatic variables (temperature and precipitation) and agricultural variables (production, harvested area, farm-gate price) for the period 1996 - 2020, which form the independent variables of the study. The estimations used 60 observations and a total of 38 estimations were run in the econometric software EViews8, of which Equation 05 of the Production Pooled Panel Model was chosen as the best. The model obtained used temperature and precipitation forecasts from Brazil's INPE (National Institute for Space Research), validated for the study area. The results indicate a concave function between potato production (t/ha), temperature and precipitation. Finally, based on the A2 climate scenario, which is the most pessimistic and using the period 2021 - 2100, a loss for potato producers of approximately 8'927,521.48 million soles was estimated.

Keywords: economic valuation; potato; yield; profitability; climate change

1. Introduction

Climate change generated as a consequence of the increase in emissions of Greenhouse Gases as a result of human activity that alters the composition of the global atmosphere and that adds to the natural climate variability observed for long periods of time, mainly affects the main climatic variables such as temperature and precipitation [6].

On the other hand, it must be taken into account that climate change will worsen the living conditions of farmers and already vulnerable and food insecure populations; rural communities, especially those living in fragile environments, face an immediate and increasing risk of crop failure, due to increasingly frequent and intense extreme weather events that represent a negative impact on food availability, access, stability and utilization [8].

In order to increase crop yields, current crops emerged and were conditioned based on the plants that are best adapted to the current climate, a process that takes about 7-10 years. This adaptation worked so well, that it resulted in the current lack of crop diversity and which, in view of climate change, now threatens food security [3].

In Peru, in the Andes area, relevant findings have emerged that warn about the tropicalization of the climate due to the increase in temperature, which is accelerating the life cycle of insects, the increase of pathogens, evidencing more diseases that in synthesis are causing havoc to crops. Likewise, the increase in CO2 emissions is increasing the sensitivity of crops to drought, acting as a fertilizer gas that causes a greater accumulation of fiber in crops and a decrease in the level of protein, therefore, they increase in size but decrease in quality [31].

Levanto, potato cultivation is fundamental in the daily life of farmers, since its production is used both for home consumption and for marketing, becoming one of their main means of economic livelihood. Therefore, it is important to predict the economic impacts that climate change would have on production in these productive areas.

Based on the above, this study predicts how climate change will generate negative economic impacts on the agricultural sector and its main objective is to evaluate the economic impacts of temperature and precipitation on potato crops, taking into account the A2 and B2 climate scenarios of the IPCC [14,15]. This will allow interpreting the impacts of climatic alterations on crop yields, expanding theoretical knowledge in this regard and thus generating a future vision of the impact of climate on potato productivity.

2. Materials and Methods

2.1. Study area

The research was conducted in the rural communities located in the districts of San Isidro del Maino and Levanto, in the province of Chachapoyas, in the Amazon region, geographically located according to Datum WGS84 UTM Z18 between the coordinates 184828 East and 9305580 North for San Isidro del Maino and 194635 East and 9295446 North for Levanto.

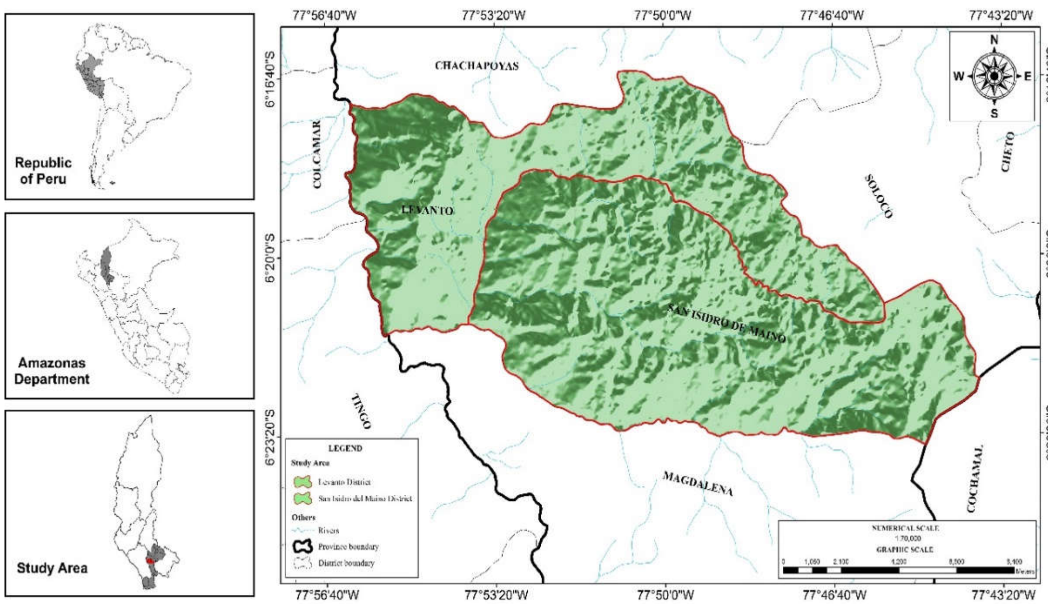

Figure 1. Location of study area.

2.2. Population

The population consisted of the total number of potato-producing Agricultural Units in the farming communities of San Isidro del Maino and Levanto by year.

2.3. Sample

Probabilistic and random sampling was performed. To determine the sample size, the formula for calculating the representative sample of a finite population applied to less than 100,000 elements was used [5]. A sample of 198 agricultural units was obtained.

2.4. Methodology

2.4.1. Data collection

2.4.1.1. Reconnaissance visit to the study area

A measurement instrument (survey) was used to collect agricultural information to build the database needed for the study.

2.4.1.2. Meteorological Information

Precipitation and temperature data were collected from SENAMHI [28]. The Chachapoyas and Leimebamba Conventional Meteorological station was used and historical data was selected for the period 1996-2020. The following parameters were taken into account:

1. Temperature:

The data series was validated using histogram plots for maximum and minimum temperature for the period 1996-2020. To generate the temperature data for the study area, the Scholz Lutz criterion was used, affecting the data by a thermal gradient factor of -5.3 °C per 1,000 meters of altitude. The values were generated taking the mean altitude of 3 060 m.a.s.l. [17].

2. Precipitation:

Rainfed agriculture is developed in the study area, so precipitation is the main source of water being important to know its spatial and temporal distribution [25].

Information from the closest stations was used, taking into account altitude, integration of the same hydrographic system (Marañón River), location of the same páramo jalca type ecosystem and that they are within the same range of isohyets [26]. The Chachapoyas and Leimebamba stations are the base stations because of their proximity to the micro-watershed. The Quebrada Shugar station was used to validate and give consistency to the precipitation data from the base stations of the study [28].

The daily total precipitation data were taken at 7 and 19 o'clock, with which the total annual precipitation was calculated [11].

2.4.1.3. Agricultural Information

Information was collected from the Ministry of Agriculture and Irrigation [22], from the Agrarian Directorate of Amazonas and from the information obtained by the measurement instrument. Historical data was selected for the period 1996-2020. The following parameters were taken into account:

- Production in tons (t).
- Harvested area in hectares (ha).
- Farm-gate price in Soles/kg.

2.5. Data analysis processing

With the temperature and precipitation data obtained, a panel database was constructed and 3 types of analysis were performed:

2.5.1. Visual graphic analysis

It was performed to determine the consistency of the information in a visual way. The historical climatic information was placed on the ordinate axis and the period of time on the abscissa axis (years, months, etc.). These histograms showed us if there were periods with doubtful or incomplete data caused by human action or natural causes and were identified by the very high peaks, jumps or trends observed in the graphs [30].

2.5.2. Double mass analysis

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Was used to identify inconsistencies caused by errors within the multiple data series and the analysis was performed between the data of the same parameter, in this case precipitation versus precipitation for the same years of information [20]. For the present case, the Chachapoyas station in Amazonas and the Quebrada Shugar station in Cajamarca were analyzed from 1993 to 2008, as well as the Leimebamba and Quebrada Shugar stations. These two groups of double mass analysis were formed with the criterion of coinciding the available years of each station.

2.5.3. Statistical analysis:

After identifying, by means of visual and double mass analysis, the periods requiring correction, the statistical analysis of jumps in both mean and standard deviation was carried out using the "T-Student" and "F-Fischer" mean tests.

Finally, the correction, completion and generation of temperature and precipitation data for the period 1996 -2020 was carried out.

2.6. Development of the regression model

The change in welfare was measured through the variation in income, which depends on the variation in production. [16].

For the potato crop, only the production function of the Ricardian model applied to agriculture was considered, which, before measuring the effect of climate change on production, measures the effect on profit [21]. In addition, it has the advantage of reducing distortion in the estimation of benefits.

$$Q_t = \beta_0 + \beta_1 S_t^j + \beta_2 P_{t-k}^j + \beta_3 TM_t + \beta_4 TM_t^2 + \beta_5 TN_t + \beta_6 TN_t^2 + \beta_7 PP_t + \beta_8 PP_t^2 + \mu_t \quad (1)$$

Where Q_t is the production in year (month) t, S_t^j is the harvested area of crop j in year (month) t, P_{t-k}^j is the real price of crop j for year (month) t-k, TM_t is the average maximum temperature of the year (month) t, TM_t^2 is the mean squared maximum temperature of the year (month) t, TN_t is the average minimum temperature of the year (month) t, TN_t^2 is the year's mean squared minimum temperature (month) t, PP_t is the precipitation of the year (month) t, PP_t^2 is the squared precipitation of the year (month) t and μ_t is the random error term.

In the function, the signs of the coefficients $\beta_3, \beta_5, \beta_7$ were expected to be positive, since it is expected that in the first years the increases in temperature and/or precipitation levels will generate an increase in crop production. On the contrary, coefficients $\beta_4, \beta_6, \beta_8$ should be negative in longer time lapses, since after these variables exceed a threshold, they will cause decreases in production levels [4].

Three types of pooled panel models were calculated with a total of 38 estimates.

1. Production Panel Model (18 estimates): Q: f (maximum T°, minimum T°, rainfall, farm gate price, harvested area) where Q= Production in metric tons (MT) [4].
2. Yield Panel Model (18 estimates): Q: f (maximum T°, minimum T°, rainfall, farm gate price, harvested area) where Q= Yield in metric tons per hectare (MT/Ha) [4].
3. Thermoperiod Panel Model (2 estimations): Q: f (Thermoperiod, precipitation, farm gate price, harvested area) where Q= Production in metric tons (MT) [4].

2.7. Regression Model Validation and Selection

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To select the best-fitting pooled panel model, we proceeded to run the 38 estimations in EViews8, then we analyzed the signs of the variables. Subsequently, the statistical significance of the variables was evaluated taking into account the T-Student statistic, whose rule states that if the ratio exceeds the value of 2 in absolute terms, it is concluded that the variable is, individually, statistically significant. In addition, the coefficient of determination or R2 was evaluated, its value ranges between 0 and 1, the closer to one, the more explanatory power the model will have. These results are obtained directly from the EViews8 software [10]. The Durbin Watson statistic, used to verify the regression error, was also evaluated. A Durbin Watson close to 2 is consistent with the absence of autocorrelation, while a value close to zero means the existence of probable autocorrelation [1]. Then, in the cases that had more than one possible equation selected, these were compared without correction taking into account the Akaike and Schwarz information criterion. The AIC criterion is a means for comparison between models, the one with the lowest Akaike and Schwarz value will be the best [10]. Finally, the selected models were validated using the error analysis criterion and a model was chosen that measures the error in relative terms, i.e. comparing the size of the error with the level of the endogenous variable [18].

2.8. Validation of the PRECIS model

PRECIS (Providing Regional Climates for Impacts Studies), allows working with regional climate models, incorporating the HadRM3P global climate model, which has 19 vertical levels and the option of two horizontal resolutions of 50 and 25 km, the first being the one used in this study and the standard resolution for large areas such as South America [19]. Marengo et al. estimated future temperature and precipitation changes in South America as a result of the PRECIS climate modeling system. These estimates include present time climate data from 1961 - 1990, and the analysis was developed using seasonal averages of observed and simulated precipitation, low and high temperature data [19]. The validity of this information was taken and the model obtained for the period 2021 - 2100 was corroborated with it, at a more local level, such as the rural communities of San Isidro del Maino and Levanto.

2.9. Creation of climate scenarios: Delta Change Method

Brazil's INPE [13] forecasts for maximum, minimum and precipitation for the IPCC [14,15], A2 and B2 scenarios were used. These data contained monthly averages of the scenarios for South America for present (1961-1990) and future (2021-2100) time periods obtained from the PRECIS regional model (HadRM3P model) with a horizontal resolution of 50km latitude-longitude [4]. Table 1 describes the main characteristics of scenarios A2 and B2:

Table 1. Characteristics of climate scenarios.

STAGE	A2	B2
Population growth	High	Medium
GDP [1]	Medium	Medium
Energy use	High	Medium
Land use changes	Medium/high	Medium
Resource availability	Low	Medium
Pace and technological direction	Slow	Medium
Preference for change	Regional	Dynamic as always

[1] GDP: Gross Domestic Product

Delta Change was calculated for precipitation, maximum and minimum temperature; for the 2021-2040, 2040-2070 and 2070-2100 scenarios. For temperature, the Delta Change for the 2021-2040 period is the difference between the average of the 2021-2040 period and the present time period 1996-2020. Delta Change for the other periods was calculated using the same procedure. For precipitation, the Delta Change of the period 2021-2040 is the difference between the average precipitation of the period 2021-2040 and the average of 1996-2020 divided by the average of 1996-2020, the obtained data was multiplied by 100 to find the percentage of variation. Delta Change for the other periods was calculated using the same procedure.

The DELTA CHANGE data calculated for scenarios A2 and B2 were used to make forecasts up to the year 2100 in the rural communities of San Isidro del Maino and Levanto, using the average data for the year 2020 as the basis.

2.10. Calculation of the economic benefit to farmers

We have: total income (TI) and total cost (TC) for the potato crop in period "t", where the profit is:

$$B_t = TI(Q_t) - TC(Q_t) \quad (2)$$

TI and TC will depend on the level of production and the profit is expected to change during period "t", due to the variation of climatic variables. Thus, we have:

$$\Delta B_t = \Delta TI_t - \Delta TC_t \quad (3)$$

If TC remains constant in period "t", then the variation in profit will be equivalent to the change in TI, having:

$$\Delta B_t = \Delta TI_t \quad (4)$$

From equation (4) it is assumed that $\Delta TC_t = 0$, this due to the assumption that in the future it is expected that the farmer will undergo a learning process where he will obtain the necessary knowledge to improve his agronomic techniques, his distribution and field management, taking actions that will allow him to reduce expenses in his productive processes [24].

The variation in total income depended on the change in production, i.e. the difference between the expected harvest in period "t" for a context of climate change ($Q_{CC,t}$) and the harvest level without climate change ($Q_{SC,t}$) for the same period of time [4]. Then keeping the price of the crop at constant real price, the TI will be:

$$\Delta TI_t = P(Q_{CC,t} - Q_{SC,t}) \quad (5)$$

Then from equation (5) we conclude that the impact of temperature and precipitation on the economic profit of potato farmers is subject to the variation of their income over time. Income was measured by the difference between the estimated harvest minus the projected harvest. The crop projection was estimated for the study area according to the A2 and B2 climate change scenarios of IPCC [14,15].

In addition, farmers' income under a scenario with climate change was estimated using temperature and precipitation projections from INPE-Brazil (Instituto Nacional de Pesquisas Espaciais) [13] for the year 2100. And the farmers' income under a scenario without climate change was estimated assuming the 2020 variables as constant until the year 2100, keeping the meteorological variables under study constant over time (no increase or decrease) until the year 2100.

For both cases, the average and constant real price of the potato crop for the period 1996-2020 was used, which was S/. 0.54 per kg of potato.

3. Results

3.1. Relationship of temperature and precipitation to the potato crop.

Based on the selection indicators, it was decided to validate and accept only the best model. Of the 38 estimates and regressions performed, the following model was selected:

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- Production Panel Model - Equation 10.

  Whose detailed equation is:

$$Q_{i,t}=-7.798019+14.32778S^{j}_{i,t}+1.378063P^{j}_{i,t}+1.076138TM_{i,t}-0.027753TM^{2}_{i,t}+0.004929PP_{i,t}-0.00000237PP^{2}_{i,t}+[AR(1)=0.651898]+\mu_{i,t} \quad (6)$$

Where $S^{j}_{i,t}$ is the harvested area of potato crop in province i and in year (month) t, $P^{j}_{i,t}$ is the real price of potato in province i for year (month) t, $TM_{i,t}$ is the maximum temperature for year t and in province i, $TM^{2}_{i,t}$ is the maximum temperature squared of year t and in province i, $PP_{i,t}$ is the total precipitation of year (month) t and in province i and μ_t is the random error term.

Table 2 shows the results of the regression to obtain the equation corresponding to the potato crop according to the EViews8 software. This model allows us to have a larger amount of data, less collinearity between variables, more degrees of freedom and increases the precision of the estimators.

Table 2. Regression results of the production panel model.

Dependent variable: PROD

Variable	Coefficient	Standard error	t-statistic	Prob.
C	-7.798019	158.1588	-0.049305	0.9609
SCOSE	14.32778	0.462537	30.97652	0.0000
PREAL(-2)	1.378063	2.917293	0.472377	0.6390
TMAX_ANUAL	1.076138	12.77805	0.084218	0.9333
TMAX_ANUAL^2	-0.027753	0.256549	-0.108179	0.9144
PPTOTAL	0.004929	0.01381	0.356908	0.7229
PPTOTAL^2	-0.00000237	0.00000685	-0.346319	0.7308
AR(1)	0.651898	0.101512	6.421894	0.0000
		Statistics		
R-squared	0.997739	Average of the dependent variable		7.978176
Adjusted r-squared	0.997371			
F-statistic	2710.637	Durbin-Watson statistic		2.641816
Prob(F-statistic)	0.000000			

These estimates included the MCG option: Cross-Section SUR and the robust errors: White Cross-Section provided by EViews

3.1.1. Temperature

Figure 2 shows the results of the best pooled-panel model, in this case Equation 10 for the potato crop in the study area, taking into account the relationship with the maximum temperature.

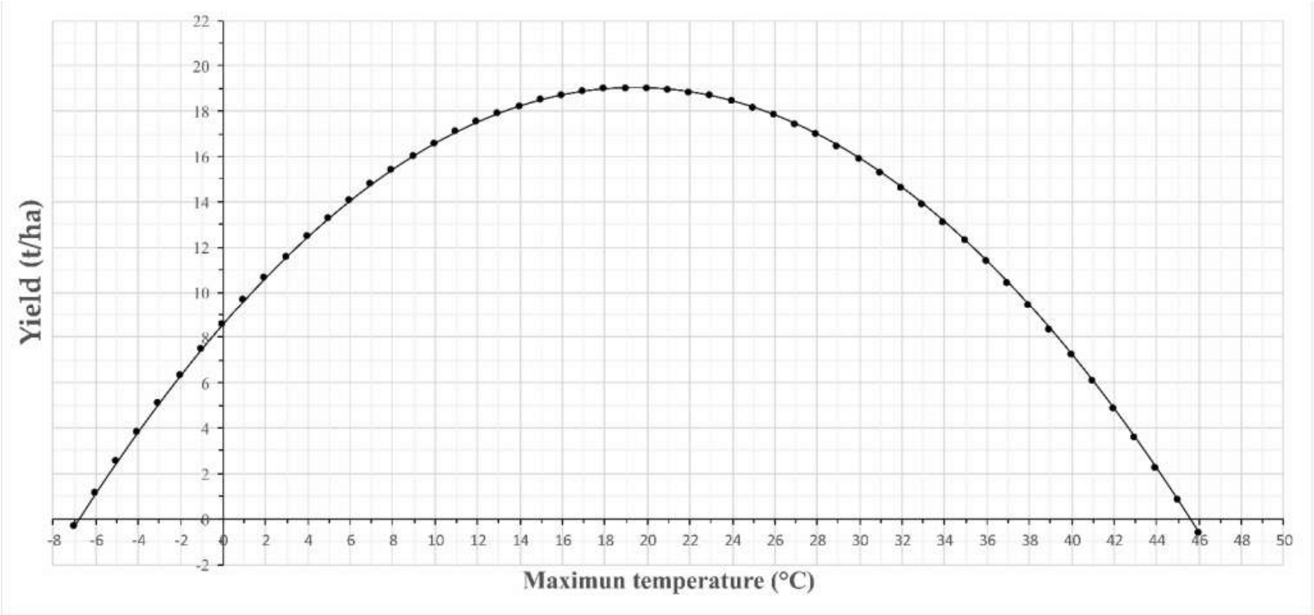

Figure 2. Potato production at maximum temperature in the study area according to the Production Panel Model Equation 10.

3.1.2. Precipitation

Figure 3 shows the best Pooled-Panel model, in this case Equation 10, for the potato crop in the study area, taking into account the relationship with Precipitation.

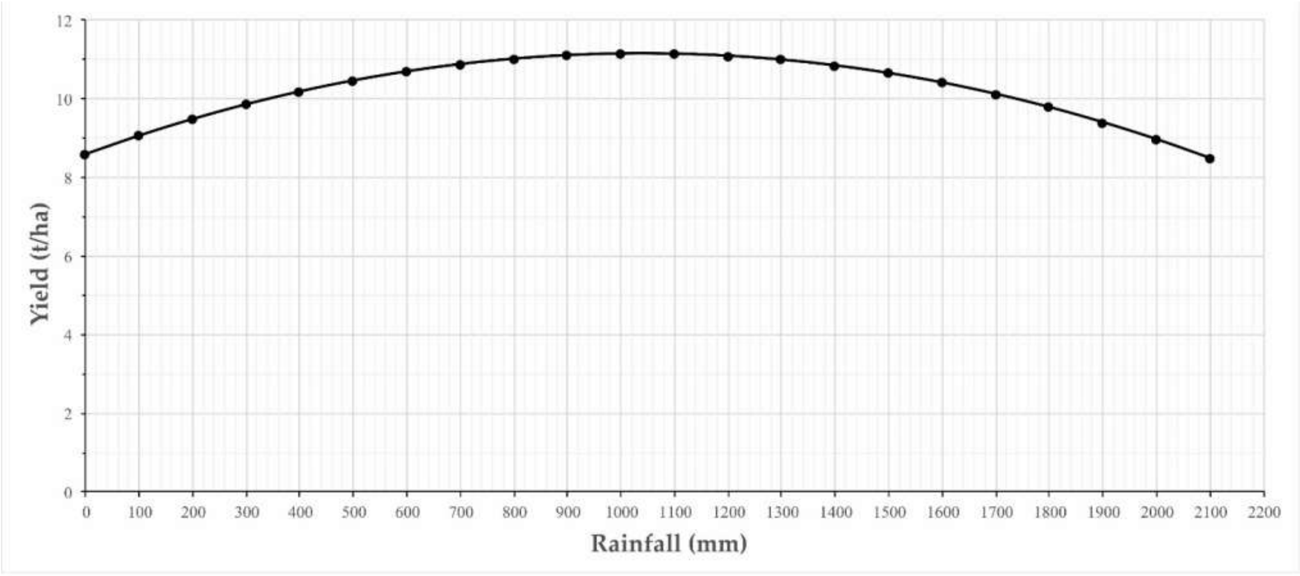

Figure 3. Potato production to total annual rainfall in the study area according to the Production Panel Model Equation 10.

3.2. Impact of temperature and precipitation on the economic income of farmers growing Solanum tuberosum up to the year 2100

The Delta Change results obtained and used to make temperature and precipitation forecasts for the period 2021-2100 are shown, i.e. the estimates of temperature and precipitation variations according to IPCC scenarios A2 and B2. It is important to mention that

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the PRECIS regional climate model used was previously validated, and the estimates used for the case of Peru were used.

Table 3. Delta Change of Maximum Temperature (°C) for climate scenario A2.

Scenario A2	Variation	Delta change maximum temperature (°C)
2020	21.03	
2040	22.37	1.34
2070	25.24	2.87
2100	30.32	5.08

Table 4. Delta Change in Precipitation (mm) for climate scenario A2.

Scenario A2	Variation	Delta change precipitation (mm)
2020	1486.83	-1.45 ANNUAL
2040	1450.58	
2070	1407.08	
2100	1363.58	

Table 5. Delta Change of Maximum Temperature (°C) for climate scenario B2.

Scenario A2	Variation	Delta change maximum temperature (°C)
2020	21.03	
2040	22.29	1.26
2070	24.26	1.97
2100	28.29	4.03

Table 6. Delta Change in Precipitation (mm) for climate scenario B2.

Scenario A2	Variation	Delta change precipitation (mm)
2020	1486.83	-1.04 ANNUAL
2040	1460.83	
2070	1429.63	
2100	1398.43	

The results of the changes in the economic benefits of farmers as a consequence of variations in temperature and precipitation for the IPCC scenarios A2 and B2 are shown below.

3.2.1. Scenario A2

The production for the year 2100 was estimated as well as the losses that will be generated in potato producers according to IPCC scenario A2.

Table 7. Final estimate of economic losses per period at constant prices (S/.) of the potato crop based on the results of the Production Panel Model Equation 10 for Scenario A2.

Periods (years)	Total loss (S/.)
2021 - 2040	142771.57
2041 - 2070	1545442.12
2071 - 2100	7239307.79
Total (2021 - 2100)	**8927521.49**

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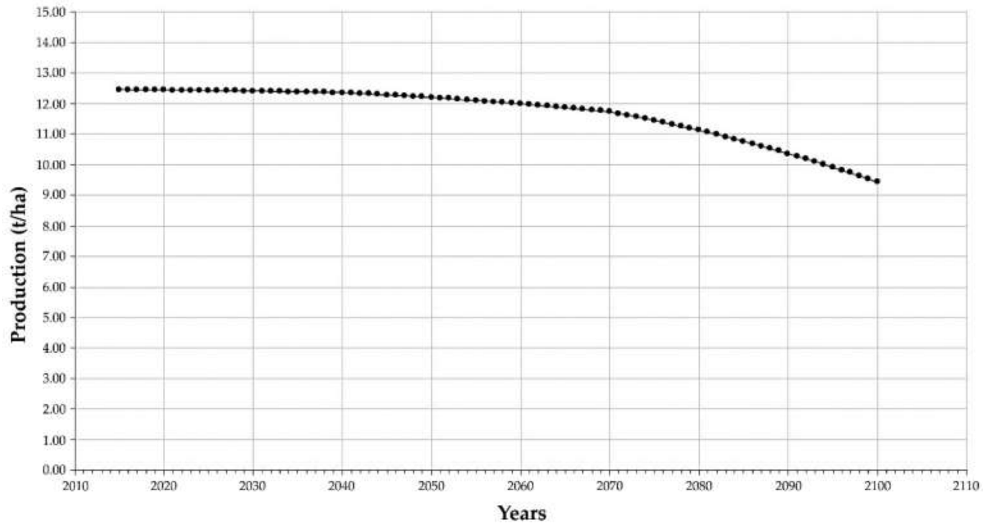

Figure 4. Potato crop production estimated for the year 2100 according to the Production Panel Model Equation 10 for scenario A2.

3.2.2. Scenario B2

The production for the year 2100 was estimated as well as the losses that will be generated in potato producers according to the IPCC B2 scenario.

Table 8. Final estimate of economic losses per period at constant prices (S/.) of the potato crop based on the results of the Production Panel Model Equation 10 for Scenario B2.

Periods (years)	Total loss (S/.)
2021 - 2040	159390.45
2041 - 2070	1115830.69
2071 - 2100	4704133.16
Total (2021 - 2100)	**5979354.30**

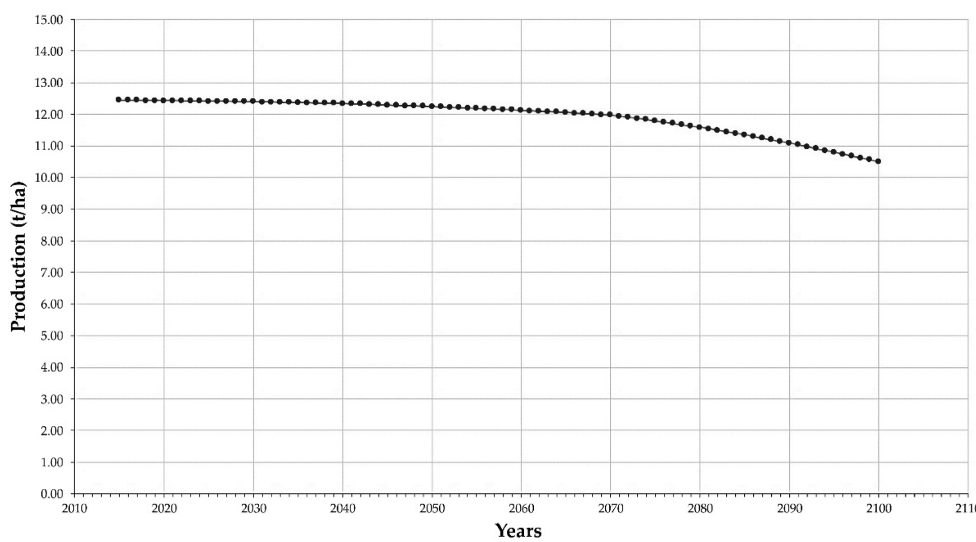

Figure 5. Potato crop production estimated for the year 2100 according to the Production Panel Model Equation 10 for scenario B2.

4. Discussion

4.1. Relationship of temperature and precipitation to the potato crop.

Production Panel Model - Equation 10:

This equation estimates that the effects of the study variables are reflected in their signs, which is in agreement with the findings of Mendelsohn and Niggol [21] in which the average temperature and precipitation variables in summer and winter have a quadratic term with a negative sign, while Schlenker and Roberts [27] conclude that, in a forward market analysis, there is a non-linear and asymmetric relationship between temperature and crop yields. Furthermore, according to Egúsquiza [7] the variables maximum temperature and precipitation have a positive linear trend at the beginning and a negative quadratic trend thereafter. In the thermoperiod panel model, the quadratic term should also have a negative sign that demonstrates the concavity of the function [7].

This study found that the coefficients of $TM_{i,t}$ and $PP_{i,t}$ have positive signs, this because in the early years increases in temperature and/or precipitation levels will generate an increase in crop production. On the contrary, the coefficients $TM_{i,t}^2$ and $PP_{i,t}^2$ have negative signs for longer time periods, since when these variables exceed their threshold, they will cause decreases in production levels, which can be observed in Figures 1 and 2.

An increase of 1 mm of precipitation before reaching the threshold limit generates an increase in production of 0.004 tons as opposed to temperature, which, when increased by 1°C, increases production by 1.076 tons. We thus conclude that the effect of temperature on potato production is greater than that of precipitation. This is due to the fact that in the study area, rainfed agriculture is practiced, that is, the rainy season from December to March is used for irrigation. [25].

The study does not present heterogeneity and the parameters have a confidence greater than 95% in their majority. The R-squared is 0.997758, indicating a high value that shows that the dependent variables explain the independent variable of production in 99.7758%, likewise the Durbin Watson obtained was 2.63, so it can be said that there are no autocorrelation problems.

4.1.1. Temperature

The relation of production with respect to temperature presents a threshold of 19°C at which a maximum production of 19.02 t/ha is reached. Likewise, at maximum temperatures lower than -7°C or higher than 45°C, potato production is equal to zero, since under these conditions it is impossible to grow. These results are in agreement with what was proposed by INTAGRI [12], which states that the temperatures that favor tuber formation are from 16°C onwards; however, from extreme temperatures higher than 25°C, tuber formation slows down and stops completely at temperatures higher than 29°C.

Equation 05 of the Production Panel model does not include the effect of minimum temperature on the potato crop, because that parameter was not found to be statistically significant. INTAGRI [12] supports the aforementioned by arguing that in Peru most potato cultivars can withstand -4°C, without suffering physiological alteration.

4.1.2. Precipitation

The increase in total annual precipitation generates increases in potato production before surpassing the threshold of Figure 2, it can reach a maximum production of 11.15 t/ha. when the total annual precipitation oscillates in 1000 mm. According to INTAGRI [12], if humidity is in deficit or excess, there will be a decrease in potato crop yields, as shown in Figure 2, with flowering and tuberization being the most affected crop stages. However, according to Bolivar [4] excellent results are obtained in rainfed potato crops with annual rainfall of 900 to 1000 mm, which corroborates the results obtained in this study.

4.2. Impact of temperature and precipitation on the economic income of farmers growing Solanum tuberosum until 2100

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4.2.1. Scenario A2

In Table 6, the economic losses to the year 2100 were estimated by the best estimate of the Production Panel Model Equation 05, under an IPCC A2 climate scenario. It should be noted that, by assuming constant prices, the proposed method could overestimate or underestimate benefits and/or losses [21].

Future values were calculated for each period based on the year 2020 and total losses were determined for the year 2100, equivalent to the sum of the losses for each period. Mendelsohn and Niggol [21] conducted a study on the impact of climate change on agriculture in South America in which they estimated losses of more than 50% of farmers' profits for the year 2100. This hypothesis is partially confirmed by the results of the present study, since the losses are around 25%, as shown in Table 6.

Table 6 shows the variation in income for the entire study area for a climate scenario A2 assuming constant real prices (base year=2020), which amounts to S/.0.54 per kg or S/.540.00 per MT. It is observed that the variation in income follows the shape of the regression model chosen for the potato crop. Therefore, complying with the concavity criterion, as temperature increases, farmers' incomes will decrease. At the end of the century, higher losses were obtained associated with a maximum temperature increase of up to 5.08°C during the period 2070-2100.

Figure 3 shows that from the year 2016 onwards, production losses are incurred; from the year 2070 onwards, potato production in the study area begins to decrease considerably as it tends to have temperatures above 25°C, this trend will continue to occur and upon reaching temperatures above 45°C it would reach a production equal to zero, due to the fact that under this condition there is no potato production.

4.2.2. Scenario B2

Table 7 shows the variation in income for the entire study area for climate scenario B2 assuming constant real prices (base year=2020). As in scenario A2, the variation in income follows the shape of the regression model chosen for the potato crop. Meeting the concavity criterion, as temperature increases farmers' incomes will decrease. However, losses are lower compared to the A2 scenario, and this is because the A2 scenario being one of the most pessimistic scenarios, considers a world with high population growth, high energy use and low availability of resources and changing technological options [4].

Then, in Figure 4, taking 2020 as the base year, it was estimated that by the year 2070 a notable and constant reduction in the profit of potato farmers in the study area begins to be seen, but it is less than the assumption of the A2 scenario.

5. Conclusions

There is a concavity relationship between potato crop production and the climatic variables of maximum temperature and precipitation. The minimum temperature of the crop does not have a major influence on production, which is confirmed by the literature consulted. As maximum temperature and precipitation increase, potato production tends to increase, however, after a threshold limit this production tends to decrease.

Maximum temperature had a greater influence than precipitation on potato crop production in the San Isidro del Maino and Levanto Rural Communities.

The highest potato crop production is obtained with a maximum temperature of 19°C and precipitation values between 1000 and 1100 mm per year according to the Production Panel Model obtained.

A final model was selected, the Production Panel Model - Equation 10. The yield and thermoperiod models did not meet the statistical and agronomic conditions for their adaptation to the study area. Thus, the Production Panel Model - Equation 10 meets all the evaluation criteria and is the ideal model to represent the future change in the benefits of the farmers of the San Isidro del Maino and Levanto Rural Communities.

For the year 2100 under an IPCC A2 climate scenario, it is estimated that potato farmers in the San Isidro del Maino and Levanto Rural Communities would have economic losses equivalent to 8,927,521.48 nuevos soles.

For the year 2100 under an IPCC B2 climate scenario, it is estimated that potato farmers in the San Isidro del Maino and Levanto Rural Communities would have economic losses equivalent to 5,979,354.30.

For the year 2100, an approximate reduction of 25% of the benefits of potato farmers in the San Isidro del Maino and Levanto Rural Communities was estimated with respect to 2020, while from the year 2070 for both scenarios A2 and B2, there is a trend with a greater decrease due to temperatures higher than 25°C.

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