Weather Variability and Kiwifruit Production in New Zealand from 2001 to 2023

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Abstract

This study identifies the effects of weather on kiwifruit production in the Bay of Plenty region in New Zealand. Kiwifruit is New Zealand's largest horticultural industry, with over 80% of the crop produced in the Bay of Plenty. However, yields have fluctuated greatly over the last decade, adversely affecting growers and the economy. The author has used panel data analysis to examine the relationship between dependent variables, green and gold varieties of kiwifruit yield (trays per hectare), and explanatory variables, including days with temperatures above 25ºC, temperatures below 0ºC, wet days, total growing degree days above 5ºC, total growing degree days above 10ºC, and winter chill hours. The analysis included fixed-effect and random-effect models and use of the Hausman test to determine the nature of weather impacts on kiwifruit yields. The findings indicate that the yields of gold kiwifruit consistently surpass those of green kiwifruit, apart from the years affected by PSA virus. Furthermore, there exists a significant inverse association between rainy days, frost days, winter chill hours, and green kiwifruit yields, respectively. Additionally, frost days further exert a substantial negative influence on gold kiwifruit. However, days with high temperatures have a markedly beneficial impact on the production of green and gold kiwifruit in the Bay of Plenty. The results highlight the importance of effectively utilizing weather data in operational decisions and in strategic choices to address the local effects of global climate change. The paper concludes with recommendations for future research.

Key Words: Weather, Variability, Kiwifruit, Production, New Zealand

1. Introduction

Kiwifruit is the largest industry within New Zealand's horticulture sector. However, it is a young industry. In the 1970s, New Zealand became the first nation outside of China to cultivate kiwifruit vines at a commercial scale. Today, the Bay of Plenty produces over 80% of the New Zealand kiwifruit crop due to its favourable growing conditions. In 2022, 13,610 productive hectares yielded over 184 million trays of kiwifruit for export from 2,843 growers (NZ Horticulture Export Authority, 2022). However, yields have fluctuated due to both weather events and plant disease. For instance, the yield in 2023 was only 163 million trays across, a decrease of 11% from the previous season (Zespri, 2024).

New Zealand continues to be a global leader in the production of kiwifruit, with a particular emphasis on the green (Actinidia deliciosa) and gold (Actinidia chinensis) varieties. The growth and quality of these crops are highly dependent on climatic factors, particularly temperature and rainfall. Given the worldwide alterations in climatic patterns, it is crucial to comprehend the potential effects of these changes on production. Both temperature and precipitation exert an impact on crucial development phases of kiwifruit, including flowering, fruit set, and maturation. Excessive exposure to cold temperatures during winter can cause a delay in the emergence of buds, while excessive precipitation can result in soil saturation, which affects the health of roots and the quality of fruits. Furthermore, fluctuations in temperature during the period of plant growth might impact the process of photosynthesis and, as a result, the growth and production of fruits.

Despite the favourable climate of New Zealand for kiwifruit production, the optimal growing conditions are sometimes disrupted by fluctuations in temperature and precipitation as a result of climate variability and climate change. Therefore, it is crucial to modify producer practices to maintain both quality and yield.

The objective of this investigation is to assess the impact of weather variables - days of high temperature, frost days, wet days, and winter chill hours in the critical kiwifruit-producing region of the Bay of Plenty. Author assesses the impact on the quality and productivity of both green and gold kiwifruit varieties. The study provides insights that should inform future cultivation strategies and management practices and so reduce the risks associated with climate change.

According to a prior study by Smith and Buwalda (2018), kiwifruit plants require minimal maintenance and are typically cultivated in temperate regions. They must be safeguarded from the extremes of heat and cold. However, kiwifruit vines are cold sensitive and should be cultivated exclusively in regions with 700 to 800 hours of chilling, i.e., the temperature in the winter should remain below 7°C for this number of hours. Not surprisingly, they thrive in locations that are situated between 800 and 1500 meters above sea level. Heat is also an issue. If temperatures exceed 35°C during the summer, leaves may become scorched.

As per Rajan et al. (2024), the kiwifruit-growing areas in New Zealand are affected by a higher occurrence of severe weather events, modified precipitation patterns, and increasing temperatures. A prior study established that overhead shade during the summer season can successfully mitigate the damage inflicted on kiwifruit by high temperatures (Wang et al., 2006). The results of previous literature have shown that climate and markets are the primary factors influencing growers' exposure, with the degree of sensitivity being influenced by geographical location. In the future, kiwifruit output is expected to be negatively impacted by warmer and drier circumstances in the North Island of New Zealand, which may further exacerbate existing vulnerabilities (Cradock-Henry, 2017).

This research identifies the effects of weather fluctuations on kiwifruit output within the Bay of Plenty region in New Zealand. For the first time, this study compares the effects of temperature and rainfall on the growth, yield, and quality of New Zealand's green and gold kiwifruit. It is also the first paper to look at how changes in the weather directly affect the yield of both green and gold varieties of kiwifruit in New Zealand. This study fills the information gap on how these two commercially relevant kiwifruit types respond to climate variability. Previous research has examined the overall effects of climate on kiwifruit production. The study uses region-specific data (utilizing data from three different weather stations) and analyses the long-term (2001–2023) changes to better understand green and gold kiwifruit vulnerabilities and resilience.

This paper commences by outlining the importance of kiwifruit yield in New Zealand and the challenges associated with the impact of climatic variables, including temperature and rainfall. The second section describes the data, whereas the fourth describes and justifies the statistical and econometric techniques employed in this analysis. The paper concludes with suggestions for the country's economic planners, policymakers, and producers, as well as future research directions that are designed to mitigate the effects of climate change on kiwifruit production. According to a prior study by Smith and Buwalda (2018), kiwifruit plants require minimal maintenance and are typically cultivated in temperate regions. They must be safeguarded from the extremes of heat and cold. However, kiwifruit vines are cold sensitive and should be cultivated exclusively in regions with 700 to 800 hours of chilling, i.e., the temperature in the winter should remain below 7°C for this number of hours. Not surprisingly, they thrive in locations that are situated between 800 and 1500 meters above sea level. Heat is also an issue. If temperatures exceed 35°C during the summer, leaves may become scorched.

2. Methodology

This research considered seasonality and used a panel analysis to examine the impact of weather fluctuations on kiwifruit production in New Zealand. The database spans the years 2001 to 2023, comprising 22 years of meteorological and yield data from several kiwifruit cultivation locations in the Bay of Plenty. The dependent variable examined in the study is the kiwifruit yield (green and gold variants separately), quantified in trays per hectare. The yearly production (trays/ha) of green (2001-2023) and gold kiwifruit (2002-2023) for several areas in the Bay of Plenty, New Zealand, has been obtained from Zespri's Annual Reports. The data includes the previous year's kiwifruit price as an explanatory variable, integrated as a lagged variable to account for price effects on production decisions. The data has been classified by location and year to align with the weather data. The explanatory variables encompass meteorological factors, including the number of days with temperatures over 25ºC, the number of days with temperatures below 0ºC, wet days, precipitation, total growing degree days at 5ºC and 10ºC, and winter chill hours. Weather data has been obtained from the National Institute of Water and Atmospheric Research (NIWA). The data were gathered from various weather stations situated in principal kiwifruit-producing areas of the Bay of Plenty, New Zealand, over a decade-long period (2001-2023). The researchers acquired data on weather occurrences in the Bay of Plenty region from the National Climate Database of NIWA, utilizing the necessary stations for the study. Owing to the absence of meteorological data, author has considered Tauranga, Te Puke, and Whakatane as the representatives of the Bay of Plenty. In addition, the humidity and precipitation data have been collected from the source of NASA POWER because of the unavailability of data in NIWA. The locale-specific weather data has been integrated with kiwifruit production statistics annually, according to geographical location and relevant time frame. This process makes a balanced panel dataset, where each observation is from a different region and year and includes variables for kiwifruit yield and different weather-related variables.

The author employed fixed effects, random effects, and the Hausman test to determine the most suitable model for policy implementation. The fixed effects (FE) model has been applied to account for region-specific variables that remain constant across time yet may influence kiwifruit production. The random effects (RE) model is estimated under the assumption that the region-specific effects are random and uncorrelated with the independent variables. The Hausman test was utilized to ascertain which panel data model (fixed effects or random effects) offers a superior match. The null hypothesis of the Hausman test posits that the random effects model is more efficient, whereas the alternative hypothesis supports the fixed effects model in the presence of correlation between unobserved regional effects and explanatory variables. The study utilized the Hausman test results to determine a suitable model for examining the influence of weather variance on kiwifruit output. Robust standard errors are employed to address potential heteroscedasticity and autocorrelation across areas across time. Fixed effects and random effects models are employed to address unobserved regional attributes (e.g., soil type or agricultural techniques) that may affect kiwifruit productivity but stay invariant over time. By employing both cross-sectional and time-series data, the dataset augments the degrees of freedom and mitigates collinearity among explanatory factors, leading to more dependable parameter estimations.

In this study, author has attempted to determine the influence of climatic factors on kiwifruit production. To find out the factors that cause the variation in the production of green and gold kiwifruit is crucial for adapting the strategies to enhance the productivity and minimize the negative effect of climate change. This section of the approach details the development of econometric models that incorporate both the immediate and lagged effects of meteorological and economic factors in order to evaluate the association between kiwifruit yields and weather variables. A thorough framework for assessing the impact of economic and weather variables on the variability of kiwifruit yields is shown by these models, which are given as Equation (i) and (ii) models. The study helps to elucidate the unique reaction of the yield of kiwifruit to weather fluctuations, providing a reasoning of how the weather shock and lagged price can affect the production of kiwifruit varieties. The research findings incorporate new dimensions in climate-resilient practice and decision-making for the future kiwifruit industry of New Zealand.

Green Kiwifruit:

$$GR_{it} = \beta_0 + \theta 1WD_{it} + \theta 2SFD_{it} + \theta 3T25_{it} + \theta 4GDD5_{it} + \theta 5GDD10_{it} + \theta 6WCH_{it} + \theta 7P_{t-1} + \theta 8L_{it} + \delta_{it} \text{ ………… (i)}$$

Gold Kiwifruit:

$$GO_{it} = \beta_0 + \theta 1WD_{it} + \theta 2SFD_{it} + \theta 3T25_{it} + \theta 4GDD5_{it} + \theta 5GDD10_{it} + \theta 6WCH_{it} + \theta 7P_{t-1} + \theta 8L_{it} + \delta_{it} \text{…………..(ii)}$$

Where:
GR = Green Kiwifruit Yield (Trays/ha);
GO = Gold Kiwifruit Yield (Trays/ha);
WD = Wet Days;
SFD = Screen Frost Days;
T25 = Days with Temperature greater than 25ºC;
GDD5 = GDD 5ºC;
GDD10 = GDD 10ºC;
WCH = Winter Chill Hours;
P = Lagged Price/Price of Previous Year;
L = Location Dummy;
δ = Error Term; β = Constant; θ = Coefficient; i = Locations; t = Years

3. Results and Discussion

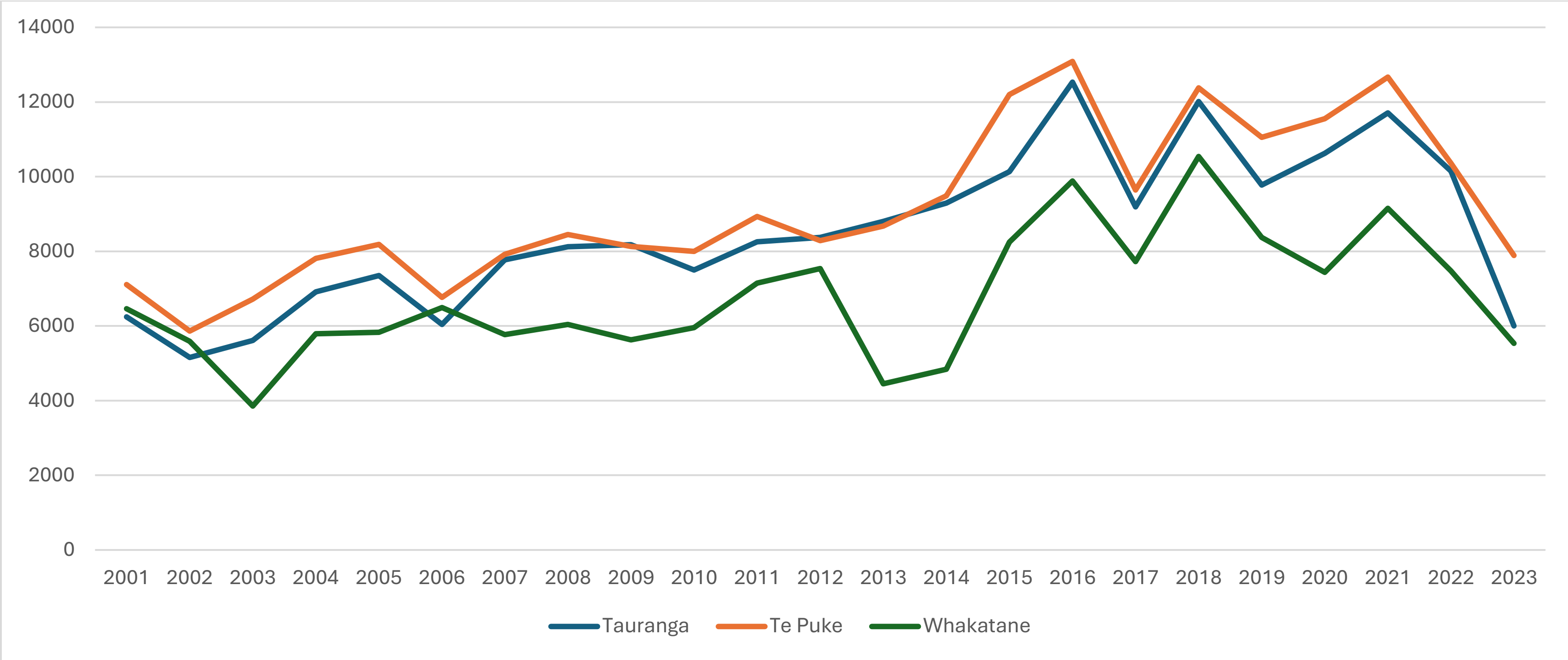
3.1 Graphical Presentation of Data

Graph 3.1: Kiwifruit Yields by Years and Varieties

Source: Zespri Annual Report, (2001-2023)

The illustration represents the annual yield of green and gold kiwifruit varieties from 2001 to 2023. Gold kiwifruit production is trending upward compared to the green type, particularly post-2015. The PSA virus caused a significant decline in output for both varieties of kiwifruit during 2013-2014. Green kiwifruit exhibits greater stability during instances of fruit illnesses. Gold kiwifruit possesses significant market demand and exhibits tolerance to climatic conditions.

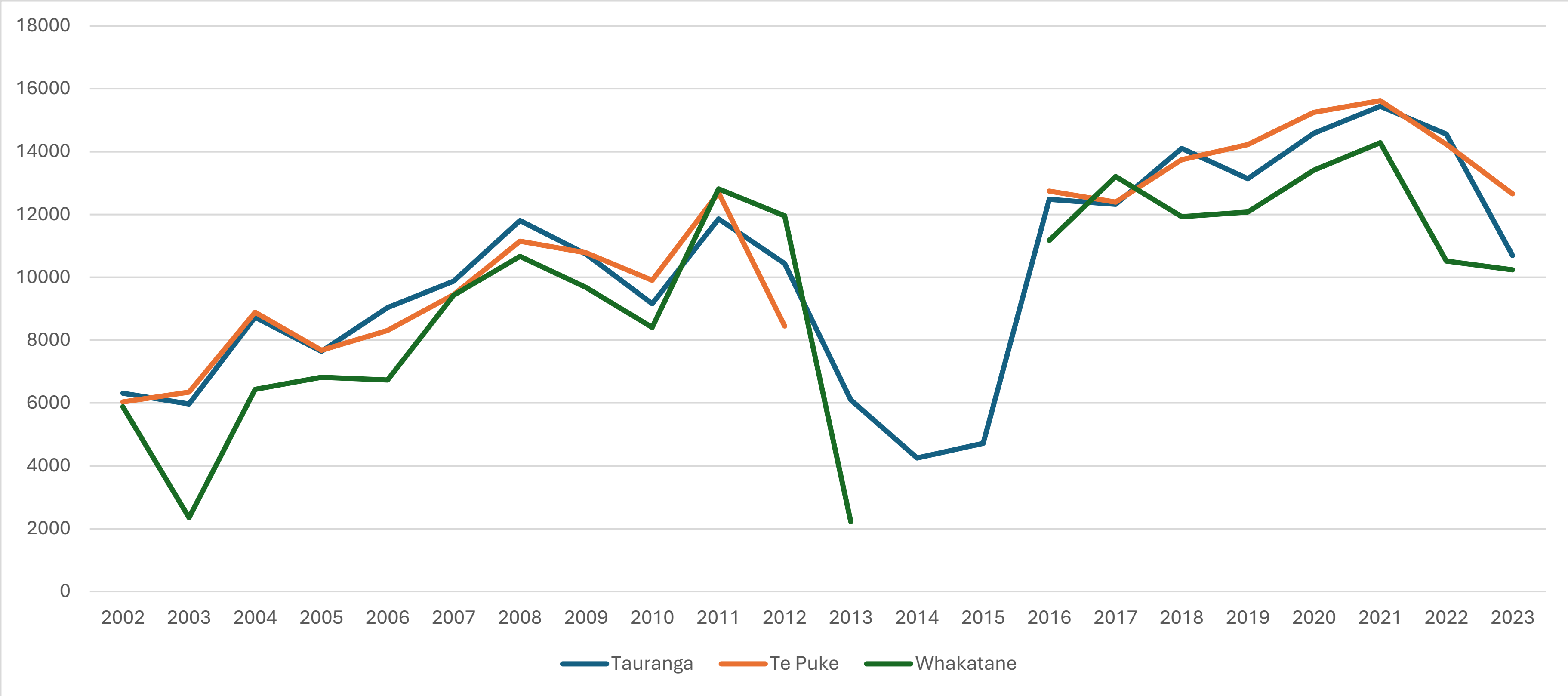
Graph 3.2: Green Kiwifruit Yield by Location



Source: Zespri Annual Report, (2001-2023)

The graph depicts the fluctuations in green kiwifruit production over the course of the years for three locations: Tauranga, Te Puke, and Whakatane. The yield of land in Tauranga experienced a significant increase from 2014 to 2016, reaching its peak in 2016. It subsequently experienced a consistent decline until 2023. Te Puke demonstrated a more consistent upward trajectory in yield, with substantial maxima occurring in 2004, 2009, 2012, and 2017. The yield of Whakatane fluctuated, with notable maxima occurring in 2002, 2006, 2009, 2011, and 2019. It experienced a substantial decline from 2019 to 2023. Te Puke consistently achieved the highest yield during the period, followed by Tauranga and Whakatane.

Graph 3.3: Gold Kiwifruit Yield by Location



Source: Zespri Annual Report, (2002-2023)

The preceding graphic illustrates the production trends of gold kiwifruit in Tauranga, Te Puke, and Whakatane throughout time. The yield of Tauranga improved considerably from 2014 to 2016 but subsequently declined till 2023. Te Puke gold kiwifruit has shown a more consistent upward trend in the years 2004, 2009, 2012, and 2017. Despite a significant decline in production in 2019 and 2023, the yield of gold kiwifruit in Whakatane reached its peak in 2002, 2006, 2009, 2011, and 2019. Over the course of 23 years, Te Puke yielded significantly more gold kiwifruit than other regions.

3.2 Summary Statistics

Table 3.1 Summary Statistics

Variables	Obs	Mean	Median	Standard Deviation	Sample Variance	Standard Error	Coefficient of Variation	Minimum	Maximum
Green Kiwifruit Yield (Trays/Hectare)	69	8155	8002	2181	4757259	263	0.27	3855	13088
Gold Kiwifruit Yield (Trays/Hectare)	61	10241	10662	3274	10721712	419	0.32	2227	15621
Green Kiwifruit Price (OGR – P/Hectare)	66	4.9	4.8	1.3	1.7	0.2	0.27	2.9	7.5
Gold Kiwifruit Price (OGR – P/Hectare)	66	8.3	7.9	2.6	6.9	0.3	0.32	4.5	12.9
GDD 5ºC (Hour)	69	3049	2534	1112	1237230	134	0.36	1982	5557
GDD 10ºC (Hour)	69	1781	1478	701	491971	84	0.39	1086	3437
Humidity at 2 Meters (g/kg)	69	38.3	38	2.7	7.5	0.3	0.07	33	45
Precipitation (MM/Day)	69	7.3	5	4.7	22	0.6	0.65	0	20
Screen Frost Day (Day)	69	3.7	2.0	4.4	19.1	0.5	1.18	0.0	17.0
Tem>25ºC (Day)	69	37.3	30.0	24.5	598.8	2.9	0.66	4.0	119.0
Wet Day (Day)	69	142.4	125.0	48.6	2357.4	5.8	0.34	78.0	263.0
Winter Chill Hour (Hour)	69	539	430	330	108918	40	0.61	68	1657

The summary statistics table explains the descriptive statistics of all kiwifruit production, price variables, and weather variables. The average green yield trays per hectare is 8155, but it is 10241 trays per hectare for gold kiwifruit. The mean price of green kiwifruit is $4.9 per hectare; on the other hand, it is $8.3 per hectare for gold kiwifruit, making the gold kiwifruit more expensive. Weather considerations include wet days, which average 142.4 days a year but can vary. Rainfall ranges from 0 to 20 mm/day, although humidity remains at 38 g/kg. Frost days average 3.7 days a year but can last 0 to 17 days. Days with temperatures >25°C are warmer, averaging 37.3 days, and vary greatly. The total heat measures, GDD5°C and GDD10°C, vary a lot between the study sites, with an average of 3,049 and 1,781 hours, respectively. Also, the average number of chill hours in the winter, which are necessary for sleep, is 539 hours. The wide range of winter chill hours, from 68 to 1,657, shows how different the climates are in the areas that were studied.

3.3 Estimation of Green Kiwifruit Model

Table 3.2: Regression Estimation of Green Kiwifruit

Explanatory Variables	Model 1 SR	Model 2 SR	Model 3 SR	Model 4 SR	Model 5 SR	Model 6 SR	Model 7 SR	Model 8 SR	Model 9 SR	Model 10 MR	Model 11 MR	Model 12 MR
$Price_{Lag}$	566.53*** (0.005)									425.37** (0.036)	302.43 (0.163)	334.95* (0.100)
Wet Days		-5.06 (0.357)								-9.43* (0.095)	-13.70*** (0.016)	-13.46*** (0.016)
Humidity			122.99 (0.206)									
Precipitation				79.39 (0.160)							-11.87 (0.820)	
Tem>25ºC					31.30*** (0.003)					24.82** (0.024)	33.55** (0.036)	
Screen Frost Days						-211.12*** (0.000)				-137.32** (0.020)		
Winter Chill Hour							-1.99*** (0.012)				-2.46*** (0.001)	-1.75** (0.024)
GDD 5ºC								0.51** (0.031)			0.31 (0.425)	-6.53** (0.044)
GDD 10ºC									0.89*** (0.018)			11.66** (0.022)
Intercept	5406.49 (0.000)	8875.33 (0.000)	3449.62 (0.354)	7578.75 (0.000)	6988.35 (0.000)	8938.45 (0.000)	9226.79 (0.000)	6600.62 (0.000)	6575.75 (0.000)	7018.24 (0.000)	7846.13 (0.000)	8526.81 (0.000)
R^2	11%	1%	2%	3%	12%	18%	9%	7%	8%	32%	37%	38%

Note: * is at 10%, ** is at 5% and *** is at 1% level of significance; Source: Authors' Compilation, 2024

The above table explores the regression result of the effect of previous year price of green kiwifruits and weather variables on the yield of green kiwifruit in Bay of Plenty. The first nine models examine the individual effect of these variables on the production, but the last three models exhibit the multiple variables influence on the production. The lagged price consistently has a significant positive effect on the green kiwifruit yields. It indicates that the price of previous years influences the current year's yields. With the high price of last year, the kiwifruit growers are more likely to invest in producing more kiwifruit; on the other hand, the lower price of the previous year may decline the investment in kiwifruit production of the current year. Economic incentives drive the production decisions of the kiwifruit industry in New Zealand.

This study has found an intriguing association between kiwifruit yields and weather variables. Though meteorological variables—days that have temperatures above 25°C have had a positive significant effect on green kiwifruit production—the frost days and winter chill hour have a significant inverse influence on the kiwifruit yields, underscoring the adverse consequences of extreme cold weather. The frost days and winter chill hours are important for kiwifruit production, but excessive adverse weather may damage the yield volume in the Bay of Plenty. Conversely, the significance of warmer weather highlights the necessity of warm climate to ensure optimal growth of green varieties of kiwifruits. The growing degree days (hours) of 5°C and 10°C exhibit positive and substantial association with the green kiwifruit yields, which indicates the importance of heat accumulation during the growing season. Particularly for Bay of Plenty, it receives benefits from climate that accumulates sufficient degree days for kiwifruit growth, supporting the positive relationship between heat and yield.

The multiple regression models have shown that price and weather factors that happen later have a positive effect on the yield of green kiwifruits in the Bay of Plenty. This helps us understand how the models work when results change over time. Here, the previous year's price retains a significant positive effect in Model 10, but it has lost significance in Models 11 and 12 due to incorporating other meteorological factors. The wet days have a significant negative effect on kiwifruit yields in three multiple regression models, and it explores how the excessive rainfall impedes kiwifruit production, presumably due to heightened risks of waterlogging and diseases. In the same way as simple regression analysis, the days with more than 25°C temperature exert a beneficial and substantial influence on the growth of green kiwifruit yield in both models. In contrast, frost days and winter chill hours have a considerable negative association with the yield, indicating the harm inflicted by low temperatures during the essential growing phases of kiwifruit. Though GDD 5°C demonstrates mixed effects, GDD 10°C has a positive significant influence, emphasizing that the cumulative warmth is essential for the growth of plants.

These findings are based on the climate attributes of the Bay of Plenty in New Zealand, where the area's moderate to heavy precipitation and sporadic frosts pose obstacles to kiwifruit cultivation. The adverse impacts of precipitation and frost underscore the crop's susceptibility to heavy moisture and frigid weather. The mild climate of the Bay of Plenty is ideal for growing kiwifruit. To mitigate adverse weather impacts and make the most of favourable climate conditions, adaptive strategies such as improved drainage systems and frost protection measures are crucial.

3.4 Estimation of Gold Kiwifruit Model (Excluded 2001, 2013, 2014, 2015)

Table 3.3: Regression Estimation of Gold Kiwifruit

Explanatory Variables	Model 1 SR	Model 2 SR	Model 3 SR	Model 4 SR	Model 5 SR	Model 6 SR	Model 7 SR	Model 8 SR	Model 9 SR	Model 10 MR	Model 11 MR	Model 12 MR
$Price_{Lag}$	646.55*** (0.000)									436.29*** (0.007)	404.55** (0.020)	429.26*** (0.012)
Wet Days		8.26 (0.342)										0.73 (0.926)
Humidity			375.56*** (0.015)									
Precipitation				152.54* (0.087)								14.77 (0.854)
Tem>25ºC					55.54*** (0.001)					43.16*** (0.014)		42.32** (0.024)
Screen Frost Days						-203.50** (0.053)						
Winter Chill Hour							-1.27 (0.330)			-2.39** (0.044)	-2.46** (0.043)	-2.40** (0.050)
GDD 5ºC								1.23*** (0.000)			0.95** (0.023)	
GDD 10ºC									2.02*** (0.000)			
Intercept	5173.49 (0.000)	9043.51 (0.000)	-4240.26 (0.468)	9062.72 (0.000)	8093.41 (0.000)	10924.42 (0.000)	10913.15 (0.000)	6394.06 (0.000)	6556.06 (0.000)	6411.08 (0.000)	5395.44 (0.000)	6284.17 (0.000)
R^2	27%	2%	10%	5%	19%	6%	2%	19%	20%	35%	35%	36%

Note: * is at 10%, ** is at 5% and *** is at 1% level of significance; Source: Authors' Compilation, 2024

In the simple regression models (1-9), each economic and climate variable's individual effect on gold kiwifruit yield is elucidated. Lagged price in Model 1 is 1% significant and has a positive effect on gold kiwifruit yield. This means that prices from previous years affect how much growers spend on inputs like fertilizers and watering, especially for a premium variety like gold kiwifruit. Furthermore, humidity and precipitation have a positive and significant influence on the production of gold kiwifruit. This indicates that moderate rainfall contributes to the health of the gold fruits, whereas excessive precipitation may not be as beneficial for the kiwifruits. Days with temperatures higher than 25°C are quite significant and have a favourable impact on yields. This is because warm temperatures are important for the growth of gold kiwifruit to its full potential. Conversely, screen frost days have a slightly significant adverse effect, which reflects the yield damage that frost can cause to crops during sensitive growth phases. The fact that the GDD 5°C in Model 8 and the GDD 10°C in Model 9 are both extremely significant and positive demonstrates the significance of accumulated heat in assisting the physiological processes of this crop that is sensitive to temperature.

The multiple regression models (10–12) estimate the accumulated influence of economic and climatic factors on gold kiwifruit yields in New Zealand. Lagged price remains positive and significant across all models, reaffirming the importance of economic incentives for growers' production decisions. The days that have temperatures that are higher than 25°C continue to have a significant and favourable influence, as was the case with the green kiwifruit table. This table investigates the crucial function that warm conditions play in causing better yields of gold kiwifruit. Even though gold kiwifruit requires less chilling than green kiwifruit varieties, the negative effect of winter chill hours across models explains the fact that excessive chilling might impair the growth of gold kiwifruits. These findings can be attributed to the Bay of Plenty's mild and warm environment, as well as to their superior orchard management procedures. The strong effect of lagged price reflects growers' responsiveness to market conditions, particularly in a high-value product like gold kiwifruit. While wet days and precipitation appear insignificant or marginally positive, the region's irrigation systems likely counteract rainfall deficiencies or excesses. The positive effects of temperature above 25°C and GDD metrics align with the region's generally warm growing seasons, which are ideal for gold kiwifruit. The marginally negative effects of screen frost days and winter chill hours highlight occasional climatic risks, particularly in colder years. Together, these results emphasize the interplay between Bay of Plenty's favourable climate and growers' ability to mitigate weather-related challenges to maintain high yields of gold kiwifruit.

3.5 Panel Analysis for Green Kiwifruit

Table 3.4: Panel Analysis Estimation of Green Kiwifruit

Explanatory Variables	Model 1 FE	Model 2 RE	Model 3 FE	Model 4 RE
$Price_{Lag}$	303.21 (0.101)	425.37** (0.033)	201.50 (0.303)	213.06 (0.331)
Wet Days	-1.74 (0.747)	-9.43* (0.090)	-6.30 (0.334)	-14.33** (0.027)
Humidity			123.66 (0.387)	-203.15 (0.114)
Precipitation			-10.02 (0.868)	64.17 (0.327)
Tem>25ºC	37.92*** (0.000)	24.82** (0.020)	0.34 (0.984)	9.97 (0.593)
Screen Frost Days	1.15 (0.988)	-137.32*** (0.017)	77.01 (0.316)	21.33 (0.795)
Winter Chill Hour			0.23 (0.838)	-2.40*** (0.015)
GDD 5ºC			-13.79*** (0.001)	-6.83* (0.065)
GDD 10ºC			23.47*** (0.000)	12.39** (0.046)
Intercept	5514.21 (0.000)	7018.24 (0.000)	3258.14 (0.000)	16069.12 (0.001)
Hausman Test	P = 0.923 > 0.05 (Insignificant) RE is preferred		P = 0.004 < 0.05 (Significant) FE is preferred	
Xttest0	P = 1.000 > 0.05 (Insignificant) There is no Heteroskedasticity		P = 1.000 > 0.05 (Insignificant) There is no Heteroskedasticity	

Note: * is at 10%, ** is at 5% and *** is at 1% level of significance; Source: Authors' Compilation, 2024

The panel analyses (Tables 5 and 6) use fixed effects and random effects for green and gold kiwifruit separately. They show how late-phase price and weather variables affect yields in different perspectives using data from New Zealand. In the green kiwifruit model estimation, lagged prices significantly and positively influence yields for the current year under the random effects (RE) model, reflecting the role of past price signals in the production decisions of the kiwifruit growers. Among weather variables, wet days negatively impact kiwifruit yields in the RE models, suggesting excess rainfall may lead to plant disease and waterlogging susceptibility. The fixed effects (FE) and random effects (RE) models continuously show a positive and significant relationship for days with temperatures over 25°C, highlighting the fact that warmer temperatures provide ideal growing circumstances for kiwifruit and increase their production. The results show that certain heat accumulations are necessary for green kiwifruit production, as winter chill hours and GDD 5°C have detrimental effects and GDD 10°C has positive effects on yields. According to the Hausman Test, models 1 and 2 are better off with a random effect ($p > 0.05$), whereas models 3 and 4 are better off with a fixed effect ($p < 0.05$). None of the models used to estimate green kiwifruit show heteroskedasticity.

3.6 Panel Analysis for Gold Kiwifruit

Table 3.5: Panel Analysis Estimation of Gold Kiwifruit

Explanatory Variables	Model 1 FE	Model 2 RE	Model 3 FE	Model 4 RE
$Price_{Lag}$	407.17*** (0.015)	429.25*** (0.008)	23.15 (0.904)	350.82* (0.065)
Wet Days			-11.83 (0.314)	-8.66 (0.432)
Humidity			563.33*** (0.016)	-6.45 (0.975)
Precipitation	12.27 (0.876)	14.72 (0.853)	-72.89 (0.428)	20.70 (0.839)
Tem>25ºC	48.96*** (0.007)	42.77*** (0.014)	-14.06 (0.619)	21.42 (0.475)
Screen Frost Days			158.68 (0.258)	142.26 (0.334)
Winter Chill Hour	-1.46 (0.362)	-2.38** (0.041)	-1.15 (0.511)	-3.27** (0.037)
GDD 5ºC			-19.40*** (0.006)	-2.81 (0.655)
GDD 10ºC			34.19*** (0.005)	6.03 (0.570)
Intercept	5831.41 (0.000)	6364.02 (0.000)	10662.81 (0.000)	6994.20 (0.000)
Hausman Test	P = 0.201 > 0.05 (Insignificant) RE is preferred		P = 0.010 < 0.05 (Significant) FE is preferred	
Xttest0	P = 1.000 > 0.05 (Insignificant) There is no Heteroskedasticity		P = 1.000 > 0.05 (Insignificant) There is no Heteroskedasticity	

Note: * is at 10%, ** is at 5% and *** is at 1% level of significance; Source: Authors' Compilation, 2024

In the above table, author also estimates the different fixed and random effect models and apply the Hausman test to measure the best estimated models in the case of gold kiwifruit. For gold kiwifruit, the lagged price has a significant positive effect in both FE and RE models, affirming its strong influence on production decisions. One of the environmental variables that has a considerable impact on yields in RE models is humidity, which demonstrates the need to maintain the appropriate amount of moisture. Temperatures higher than 25°C have a positive impact on yields as well, highlighting the importance of warm temperatures in the development of gold kiwifruit. The winter chill hours, on the other hand, have been shown to have significant negative impacts in random models, which suggests that excessive chilling leads to negative consequences. The GDD measurements show mixed results: GDD 5°C has a negative effect on yields in the FE model, but GDD 10°C has a positive effect on yields in the RE model, which is in line with what gold kiwifruit needs to grow. There is a preference for the random effect between Model 1 and 2 ($p > 0.05$), whereas the fixed effect is favoured between Model 3 and 4 ($p < 0.05$). This preference is based on the Hausman test evaluation. There are no heteroskedasticity problems discovered in any of the models.

Different climatic sensitivity has been revealed by the analysis when comparing the estimations of green and gold kiwifruit varieties in the Bay of Plenty of New Zealand. Due to its growth requirements and vulnerability to adverse weather circumstances, green kiwifruit seems more sensitive to wet days and winter chill hours. Gold kiwifruit, on the other hand, adjusts to constant wetness and benefits from greater humidity levels. Gold kiwifruit exhibits a more consistent favourable response, especially when the PSA-affected years are excluded, but both types have expected yields in warmer climates and react favourably to GDD 10°C. These results highlight how important it is to modify climate management strategies for the growers in this time to maximize kiwifruit yields for the green and gold kiwifruit varieties in the Bay of Plenty area. This is essential because kiwifruit from New Zealand is a large export crop, with 80% of the fruit produced in the Bay of Plenty.

4. Concluding Remarks and Policy Recommendation

4.1 Conclusion

This study demonstrates how changes in the weather and the economic factors affect the production of green and gold kiwifruit in New Zealand, specifically in the Tauranga, Te Puke, and Whakatane regions of the Bay of Plenty from 2001 to 2023. She has taken the weather data from NIWA, NASA Power, and the yield and price data of both kiwifruit varieties from Zespri Annual Reports. Author has prepared the panel data for these three locations over 23 years. This study employs both simple and multiple regression analysis, as well as panel data analysis, which includes both fixed and random effects. She has conducted the Hausman test to determine the most suitable model for this study. The price from previous years consistently influences the decision to produce kiwifruit in the current year. Using panel analysis, the study shows that important weather factors like wet days, days with temperatures above 25°C, frost days, winter chill hours, and growing degree days have a big impact on kiwifruit yield. The findings explore that while warm temperatures and adequate GDD positively impact production, extreme weather conditions, including excessive frost days and prolonged wet periods, adversely affect kiwifruit yield quality and quantity. Author also observed differences between green and gold kiwifruit, with the latter demonstrating greater resilience to temperature extremes but greater sensitivity to winter chill hours. Both varieties demonstrate positive responses to temperatures above 25°C and GDD 10°C, reflecting the critical role of heat accumulation during the growing season. Moreover, economic factors, including lagged prices, have significantly influenced production decisions, highlighting the interplay between environmental conditions and market dynamics. These results underscore that kiwifruit production is very sensitive to changes in the weather. To keep kiwifruit yields high when the weather changes, farmers need to come up with flexible farming methods.

4.2 Recommendations

To protect the kiwifruit industry of New Zealand against the adverse effect of climatic variability, a multi-pronged strategy is essential. In Bay of Plenty, the kiwifruit growers should take actions to mitigate and enhance adaptability with adverse weather conditions, especially by using frost protection, breeding more hardy kiwifruit varieties, and improving irrigation systems. The farmers should consider wind machines, sprinklers, or heaters to prevent frost damage. To improve the drainage systems, the field should be designed with effective drainage to manage the excess water and prevent root rot. It may develop the quality and quantity of kiwifruit yield if producers use the benefits of warmer temperatures over longer periods of time. At the time of excessive heat, they should install shade nets and apply evaporative cooling to protect the fruits. The kiwifruit producers should gradually prune and maintain air circulation within orchards to decrease humidity levels. They should develop and try to investigate new kiwifruit varieties with lower chill hour requirements, though the result has shown a negative association between winter chill hours and kiwifruit yields in the Bay of Plenty. To ensure appropriate resource utilization and increase output, customized fertilizer, soil management, and insect as well as disease protection procedures should be applied appropriately. To protect against climate-related risks, policymakers should think about offering economic benefits like crop insurance and helping with diversification by conducting more research on different varieties of kiwifruit. The kiwifruit industry requires robust governmental assistance to develop infrastructure resilient to climate change, facilitate the adoption of sustainable agricultural practices, and promote long-term planning among farmers in New Zealand. The New Zealand kiwifruit sector is anticipated to address and adapt to weather variability challenges, maintaining its status as a global leader in high-quality kiwifruit production in the future.

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