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The Effect of Climate Change on Milk Yield in New Zealand: A Case Study of Fonterra

Research Article

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ABSTRACT

Climate change affects milk yield, which may have a profound impact on the dairy industry. Taking Fonterra as an example, this study analyses the climate data of 99 consecutive months from June 2012 to August 2020 and the corresponding monthly milk yield data of North Island and South Island. The results show that the monthly milk yield correlates with the monthly mean temperature, the monthly extreme maximum temperature, the monthly extreme minimum temperature, the monthly mean relative humidity, and the monthly mean temperature and humidity index (THI). In addition, with the increase of annual mean temperature in New Zealand, the annual milk yield of North Island decreases with the increase of temperature. Fonterra needs to take measures to mitigate the negative impact of climate warming on milk yield. However, in the recent nine years, South Island's annual milk yield increases with annual mean temperature. Furthermore, regression equations with climate factors as independent variables and monthly milk yield as dependent variables are established for North Island and South Island. In North Island, the monthly milk yield changed periodically with time. The findings of the study show that the annual milk yield will decrease with the increase of temperature due to global warming in North Island. However, South Island needs to deal with the negative impact of high temperature on milk yield in summer. Therefore, Fonterra needs to take immediate measures to deal with the negative impact of climate change.

KEY WORDS climate change, humidity, milk yield, New Zealand, temperature.

INTRODUCTION

Milk is a nutritious food with a long history. Dairy products provide high-quality protein, vitamins, and minerals. Globally, dairy products contribute 10% protein, 9% fat, and 5% energy to the human diet (Dairy Reporter, 2020). The number of cows in the world is 278 million (World Wildlife Fund, 2019). There are 133 million dairy farms in the world. The dairy industry has made efforts to improve energy efficiency, reduce greenhouse gas emissions, and achieve individual results (Dairy Reporter, 2020). Climate change has a direct and indirect impact on the milk yield of dairy cows. There is significant climate change over the past few decades. Climate change directly impacts the milk yield of dairy cows and can also indirectly affect the milk yield of dairy cows by affecting crop yields and increasing the spread of diseases (Gauly *et al*. 2013; Ranli *et al*. 2017). Thermal stress caused by high ambient temperature can harm milk yield, reproductive capacity, and health of dairy cows and cause the death of cows (Hristov *et al*. 2017; Ouellet *et al*. 2019). In addition, the global decline in grain production caused by climate change has resulted in insufficient feed for dairy cows, which also indirectly affects milk yield (Silanikove and Koluman, 2015). The changes in temperature also impact pregnancy of cows which affects milk yield as well (Sartori *et al*. 2010; El-Wishy, 2013).

The U.S., the world's largest exporter of food and feed, is expected to experience negative impacts from climate change (Brown *et al*. 2015). Grain production in Europe is expected to decline due to climate change (Teixeira *et al*. 2013). The shortage of feed has led to a rise in prices, which has also increased costs in the dairy industry. Simultaneously, the rise of temperature increases the occurrence of animal husbandry diseases (diseases are transmitted by vectors such as flies, and the increase of temperature is conducive to the reproduction of flies) (Moreki and Topito, 2013). In addition, climate change affects forage yield and quality, and forage quality affects milk yield by affecting the protein intake of dairy cows (Hristov *et al*. 2017; Dellar *et al*. 2018; Ergon *et al*. 2018). Some scholars put forward measures to deal with the impact of climate change on milk yield. Which includes cultivating heat resistant dairy cattle varieties and grass seeds with strong adaptability (Scharf *et al*. 2010; McManus *et al*. 2011; Silanikove and Koluman, 2015); scientifically arranging breeding and calving time (Mote *et al*. 2016; Bedhiaf-Romdhani and Djemali, 2017); providing thermal facilities to cope with cold stress (Brouek *et al*. 1991; Tucker *et al*. 2007); adjusting feed composition, proportion and feeding time (Brandt *et al*. 2018; Herbut *et al*. 2018; Dunshea *et al*. 2019); upgrading hardware facilities and providing cooling equipment (Yadav *et al*. 2016; Sinha *et al*. 2017; Kendall *et al*. 2006).

Dairy industry in New Zealand

Dairy farming is the fifth-largest industry in New Zealand and the largest export sector in New Zealand (Dairy Companies Association of New Zealand, 2020). Its output value accounts for 3.1% of Gross Domestic Product (GDP), reaching 8.2 billion US dollars. The industry has created 46000 jobs. More than 95% of the products are exported to more than 100 countries and regions globally, and the export revenue reaches 17.2 billion US dollars (Dairy Companies Association of New Zealand, 2020). Suitable climatic conditions are essential for the prosperity and development of animal husbandry in New Zealand. New Zealand has plenty of light, precipitation, and fresh air. These factors have laid the foundation for the development of the dairy industry. When climate conditions (such as drought, high temperature, etc.) affect the milk yield of dairy cows, the dairy industry's normal production will be affected. That will also affect the profits of the industry. Addressing climate change is one of the most challenging issues the dairy industry is facing. Fonterra, as a world-famous dairy brand, export value accounts for 25% of New Zealand's total export value (Fonterra Dairy Cooperative, 2020). It supplies dairy products to one billion people per day. It provides many jobs, with more than 10000 dairy farmers and 22000 employees worldwide (Fonterra Dairy Cooperative, 2020). In 2019, the sales volume reached NZ $20.1 billion, creating huge tax revenue for the government (Fonterra Dairy Cooperative, 2020). Its export value accounts for about 25% of New Zealand's total export value. Fonterra exports about 95% of its local products to more than 140 countries (Fonterra Dairy Cooperative, 2020). It is the largest organisation in New Zealand and represents New Zealand's green and pureness, which is deeply loved by global consumers. The impact of climate change on the organisation affect the economic and social development of New Zealand as a whole.

Fonterra is committed to protecting the land and environment for future generations. This is why Fonterra attaches importance to the impact of climate change and actively responds to climate change. Fonterra accounts for about 20% of New Zealand's total greenhouse gas emissions. 89% of these emissions come from farms, 10% from manufacturing, and 1% from distribution (Fonterra Dairy Cooperative, 2020). Fonterra is one of the world's most carbon-efficient dairy producers. New Zealand needs to emit 0.91 kg of carbon dioxide to produce a litre of milk. This is about one-third of the global average of 2.5 kg and is 30% lower than the carbon dioxide emissions from milk production in Europe and the United States (Fonterra Dairy Cooperative, 2020). In the past 25 years, New Zealand has reduced its farms' emission intensity by about 20%, but Fonterra has higher requirements and a sense of social responsibility (Fonterra Dairy Cooperative, 2020). Its efforts to reduce the dependence on fossil fuels in the manufacturing and transportation sectors and actively seek clean energy. That includes the use of hydro, wind, and geothermal power. It also improves the efficiency of coal utilisation by reforming its boilers. The ultimate goal is to replace fossil fuels with renewable energy. Fonterra is also looking for ways to reduce animal emissions. Fonterra has set three climate change goals: reducing 30% of manufacturing emissions by 2030, zero-emissions from production bases by 2050, and no net increase in greenhouse gas emissions from farms from 2015 to 2030 (Fonterra Dairy Cooperative, 2020).

Impact of climate change on Fonterra’s milk yield

If climate change leads to a decline in Fonterra's milk yield, it will affect the company's performance and affect the economic and social development of New Zealand. For many years, Fonterra's annual export value accounts for 25% of New Zealand's total export value (Fonterra Dairy Cooperative, 2020). According to the temperature and humidity index theory, when the temperature and humidity index (THI) is greater than 72 (temperature 25 ˚C, relative humidity 50%), the milk yield of dairy cows will decrease. In the context of global warming, the rise of THI is likely to directly affect the organisation's performance, leading to the decline of Fonterra production and the loss of jobs. That will indirectly affect New Zealand's economy and society. Therefore, it is vital to study the effect of temperature and humidity on Fonterra dairy cows' milk yield. In addition, the abnormal precipitation also affects the milk yield and fresh milk quality of dairy cows. For example, drought in Auckland is one of the most serious in modern times (NIWA, 2020), directly affecting the quality of grass. Moreover, forage is the primary food source of New Zealand dairy cattle, and 96% of its food source is grass, and only 4% of its food is imported feed (Fonterra Dairy Cooperative, 2020). Abnormal precipitation affects the food intake of dairy cows. The decrease in grassland quality caused by precipitation led to a decrease in dairy cows' food intake. It is also important to study the relationship between precipitation and milk yield.

The research questions are: what are the impacts of climate change on Fonterra's local milk yield? What are the effects of temperature, relative humidity, precipitation, and temperature and humidity index (THI) on dairy cows' milk yield in Fonterra? What measures can be taken to ensure the milk yield of Fonterra in the wake of climate change?

This research aims first to analyse the influence of temperature, relative humidity, precipitation, and THI on milk yield. Secondly, prediction modules of monthly mean temperature, monthly mean humidity, monthly rainfall, and monthly milk yield will be established, and the future milk yield will be predicted by using a weather forecast. Thirdly, countermeasures will be suggested to ensure Fonterra's milk yield in the context of climate change. Furthermore, multiple linear regression equations of monthly average temperature, monthly average humidity, monthly total rainfall, and monthly milk yield will be established. Fonterra can bring the weather forecast data into the regression equations to estimate the future monthly milk yield. It is important for Fonterra to forecast the milk yield in the future. The reason is that Fonterra needs to estimate its future milk yield, based on which to plan its production, transportation, inventory, sales, and financial work. Finally, this research will propose measures to deal with the impact of climate change on the milk yield of dairy cows. Fonterra needs to ensure its fresh milk yield before it can continue to contribute to New Zealand's economic and social development.

MATERIALS AND METHODS

In this study, multiple sources secondary data are used, including monthly milk yield data collected from global dairy update of Fonterra (including monthly milk yield data of North Island and South Island) and data of temperature, relative humidity, and precipitation collected from a meteorological database of the National Institute of Water and Atmospheric Research (NIWA). The data is freely available to all. This also ensures the availability of the data. Moreover, these data are also reliable. The data of Fonterra and NIWA are authentic. The data needed include the monthly milk yield data of North Island and South Island in the recent nine years, and the corresponding monthly extreme maximum temperature, extreme minimum temperature, monthly mean temperature, monthly mean relative humidity, monthly total rainfall, and monthly mean THI calculated by temperature and relative humidity, with a time scale of nearly nine years.

NIWA

NIWA was established in 1992. Its purpose is to enhance the economic value of New Zealand's water resources and environment, increase people's understanding of climate and atmosphere, and improve their adaptability to weather and climate hazards. The total revenue of NIWA in 2014-2015 was NZ $126.3 million (NIWA, 2020). Of these, 51% came from the Ministry of Business, Innovation, and Employment, and 12% from the Ministry of Primary Industries. The rest came from central and local governments as well as private organisations (NIWA, 2020). NIWA chairs the Secretariat of the New Zealand Centre for climate change. NIWA and Massey University, University of Canterbury, and Victoria University of Wellington jointly launched the New Zealand climate change centre. NIWA is also one of the few UK met's core partners. It also cooperates with the US Geological Survey to carry out scientific and technological cooperation in the field of water resources. NIWA's climate and atmosphere, ocean, freshwater, and environmental data are maintained by 697 employees (NIWA, 2020).

Climate data

The specific meteorological observation station information is as follows. Auckland, Taupo, and Palmerston North are selected in the North Island. These three areas are distributed in the north, middle, and south of the North Island in turn. The climate of the North Island is represented by the average of the meteorological data of the three regions. In the same way, Nelson, Hokitika, and Dunedin of South Island are also selected in this study. They are located in the north, middle, and south of the South Island in turn. The average of the above three regions' climate data represents the climate of the South Island. After averaging all the data (a total of 7920), the data of 99 rows and 5 columns in North Island and South Island was collected, respectively. Among them, 99 rows represent the number of months, and 5 columns represent climate data, which are monthly mean temperature, monthly extreme maximum temperature, monthly extreme minimum temperature, monthly mean relative humidity, and monthly total rainfall. Then the monthly mean THI is calculated according to the monthly mean temperature and relative humidity. THI can be estimated by the following formula, THI= (1.8×T+32) − (0.55−0.0055×RH) × (1.8×T−26) (Kendall *et al.* 2006). T represents temperature, and RH represents relative humidity. The final data is 99 rows and 6 columns of North Island and South Island, respective.

Milk yield data

Monthly milk yield data is from Fonterra official website. In the global daily update under the investor menu on the home page of Fonterra's official website, all files can be downloaded in PDF format. I will provide all PDF documents in the attachment. Taking the document (Global Dairy Update September 2020) as an example, it shows that Fonterra's local total milk yield (100.7 million kgMS), North Island's milk yield (73.5 million kgMS), and South Island's milk yield (27.2 million kgMS) in August 2020, kgMS with the meaning of kilogram of milk solids. As of October 29, 2020, the latest document is Global Dairy Update September 2020, so the milk yield data collected in this study is up to August 2020.

Fonterra does not release the file every month, but the missing data can be obtained by calculation. For example, Fonterra does not release the document Global Dairy Update December 2019, so there is no data directly reflecting the milk yield in November 2019. However, Fonterra displays the total milk yield data of North Island and South Island from June to December 2019 in the document Global Dairy Update January 2020. Moreover, milk yield data for June, July, August, September, October, and December of 2019 can be found directly from their respective documents. Therefore, the milk yield of the North and South Islands in November 2019 can be obtained by subtraction calculation. The milk yield of the North and South Islands in August 2014 and November 2018 can be obtained by the same way.

The data of November 2012, May, July and August 2015 can be also obtained by calculating. These global dairy update documents not only show the month milk yield data of North Island and South Island, but also compare with the milk yield data of the same month of last year. For example, according to the document Global Dairy Update September 2016, the milk yield of North Island in August 2016 decreased by 6.4% compared with that in August 2015, and that in South Island in August 2016 decreased by 0.7% compared with the same period in 2015. Therefore, through the milk yield data in August 2016, I can calculate the milk yield data of North Island and South Island in August 2015. Similarly, I can calculate the milk yield data in October and November 2012, May and July 2015.

The data from July to September and December 2012 are also obtained by calculating. According to the document Global Dairy Update July 2013, the milk yield of North Island is 7.3 million kgMS in June 2012, and that of South Island is 2.37 million kgMS. The document Global Dairy Update August 2013 shows that the total milk yield of North Island in June and July of 2012 is 24.8 million kgMS, and that of South Island in the same period is 20.9 million kgMS. By subtracting the June milk yield from the total milk yield in June and July from the above two documents, I can get the milk yield of North Island (13.6 million kgMS) and South Island (1.6 million kgMS) in July 2012. Moreover, the document Global Dairy Update September 2013 shows the total milk yield data from June to August 2012.

I can get the milk yield data of August 2012 by subtracting the total milk yield data of June and July from the total milk yield data of June, July, and August. Similarly, the document Global Dairy Update October 2013 shows the total milk yield data from June to September 2012. The milk yield data in September 2012 can be obtained by subtracting the milk yield data of June to August from the data of June to September. Furthermore, the document Global Dairy Update February 2014 contains the total milk yield from June 2012 to January 2013. The milk yield of North Island and South Island in December 2012 can be obtained by subtracting the data of other known months from the total data of Jun to January. Data for other months can be obtained directly from global dairy update documents. The final data is the monthly milk yield of North Island and South Island for 99 consecutive months from June 2012 to August 2020.

Data analysis

These data include monthly extreme maximum temperature, monthly extreme minimum temperature, monthly average temperature, monthly average relative humidity, and monthly total precipitation. The correlation coefficient between the five factors and the monthly milk yield and the correlation coefficient between THI and milk yield were calculated to verify the theory of temperature and humidity index.

In this study, multiple linear regression models of monthly milk yield, and monthly mean temperature, monthly mean relative humidity, monthly precipitation, and monthly mean THI were also established. Excel can calculate the correlation coefficient. Excel is also commonly used for multiple linear regression. The time scale in this research is 9 years, and the amount of data is within the normal range. The regression equation is established to predict future milk yield of North Island and South Island.

Proposed hypotheses

When THI exceeds a certain range, it has a negative impact on milk yield (Kekana *et al*. 2018; Ali, 2016; Das *et al*. 2016; Marami Milani, 2016; Marami Milani *et al*. 2016; Mote *et al*. 2016; Bekele, 2017; Hill and Wall, 2017; Wildridge *et al*. 2018; Zare-Tamami *et al*. 2018; Mylostyvyi and Chernenko, 2019). Based on these studies, the following hypothesis can be developed:

H1: THI has a negative effect on the milk yield of New Zealand dairy cows in summer.
$H_0$1: THI has no negative effect on the milk yield of New Zealand dairy cows in summer.

Temperature affects the milk yield of dairy cows. When the temperature exceeds the normal range, the milk yield will decrease (Balhara *et al*. 2001; Mote *et al*. 2016; Barash *et al*. 2001; Veissier *et al*. 2018; Herbut *et al*. 2018; Hristov *et al*. 2017; Dunshea *et al*. 2019). In line with previous studies, the following hypothesis is developed:

H2: Monthly extreme maximum temperature, monthly mean temperature, and monthly extreme minimum temperature affect milk yield of New Zealand dairy cows.
$H_0$2: Monthly extreme maximum temperature, monthly mean temperature, and monthly extreme minimum temperature has no affect milk yield of New Zealand dairy cows.

There is a relationship between relative humidity and milk yield (Sae-tiao *et al*. 2017; Mylostyvyi and Chernenko, 2019). It can be assumed that:

H3: Relative humidity affects the milk yield of New Zealand dairy cows.
$H_0$3: Relative humidity has no affects the milk yield of New Zealand dairy cows.

Sunshine affects milk yield (Mote *et al*. 2016; Mylostyvyi and Chernenko, 2019). It is possible to assume that:

H4: Sunshine affects the milk yield of New Zealand dairy cows.
$H_0$4: Sunshine does not affect the milk yield of New Zealand dairy cows.

Precipitation affects the milk yield of dairy cows (Stull *et al*. 2008; Tata *et al*. 2012; Mirara and Maitho, 2013; Sloat *et al*. 2018). There is a negative correlation between total monthly precipitation and milk yield on test days (Stull *et al*. 2008). However, there is also an opposite argument that monthly milk yield is positively correlated with the rainfall of the previous month (Mirara and Maitho, 2013). Based on these studies, it can be hypothesized:

H5: Total monthly precipitation affects the milk yield of New Zealand cows.
$H_0$5: Total monthly precipitation does not affect the milk yield of New Zealand cows.

RESULTS AND DISCUSSION

North Island

Monthly milk yield and monthly mean temperature

When n is equal to 99, and alpha is 0.01, the critical value of correlation coefficient significance is 0.25522. The correlation coefficient between monthly milk yield and mean temperature is +0.450873. Therefore, the correlation coefficient is significant at the level of 0.01. Because 0.3 ≤ | r | < 0.5, the correlation coefficient indicates that the monthly milk yield and the mean monthly temperature in the North Island have a moderate to low linear correlation. It can be seen from Figure 1, the maximum value of monthly milk yield appeared in October 2014, which was 147 million kgMS, corresponding to the monthly mean temperature of 12.7 ˚C. The minimum value of monthly milk yield appeared in June 2013, which was 6.3 million kgMS, corresponding to the monthly mean temperature of 9.7 ˚C.

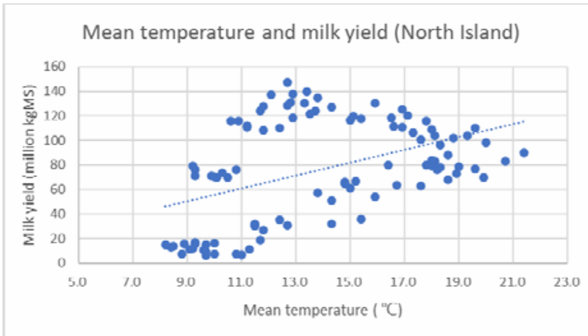

Figure 1 Monthly mean temperature and milk yield (North Island)

Monthly milk yield and monthly extreme maximum temperature

The correlation coefficient of monthly milk yield and monthly extreme maximum temperature is +0.467651. When n is equal to 99, and alpha is 0.01, the critical value of correlation coefficient significance is 0.25522. Therefore, the correlation coefficient is significant at the level of 0.01. Because 0.3 ≤ | r | < 0.5, the correlation coefficient indicates that the monthly milk yield and the monthly extreme maximum temperature in the North Island have a moderate to low degree linear correlation. As can be seen from Figure 2, the maximum monthly milk yield of 147 million kgMS corresponds to the extreme maximum temperature of 22 ˚C. The minimum value of milk yield is 6.3 million kgMS, and the corresponding extreme maximum temperature is 18.1 ˚C.

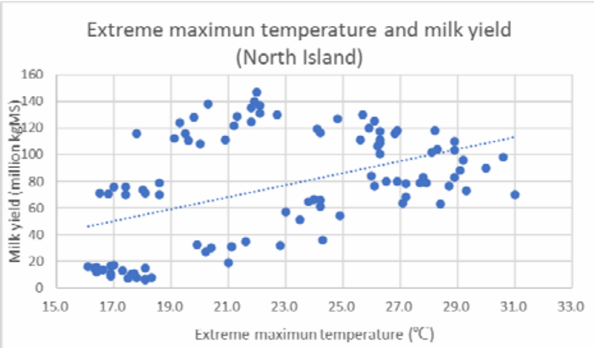

Figure 2 Monthly extreme maximum temperature and milk yield (North Island)

Monthly milk yield and monthly extreme minimum temperature

The correlation coefficient between monthly milk yield and monthly extreme minimum temperature is +0.451516. Because 0.3 ≤ | r | < 0.5, the correlation coefficient indicates that the monthly milk yield and the monthly extreme minimum temperature in the North Island have a moderate to low linear correlation. When n is equal to 99, and alpha is 0.01, the critical value of correlation coefficient significance is 0.25522. Therefore, the correlation coefficient is significant at the level of 0.01. It can be seen from Figure 3, the maximum milk yield is 147 million kgMS, and the corresponding extreme minimum temperature is 1.1 ˚C. The minimum value of milk yield is 6.3 million kgMS, and the corresponding extreme minimum temperature is -1.1 ˚C.

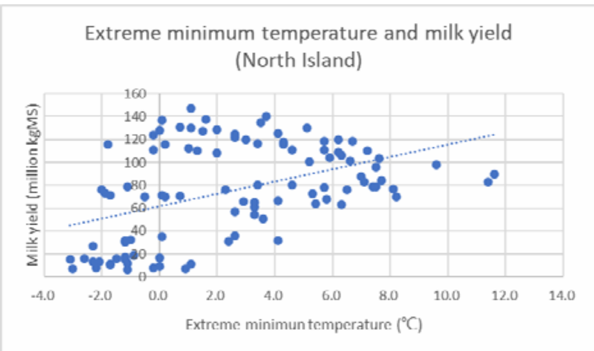

Figure 3 Monthly extreme minimum temperature and milk yield (North Island)

Monthly milk yield and monthly relative humidity

When n is equal to 99, and alpha is 0.01, the critical value of relative coefficient significance is 0.25522. The correlation coefficient between monthly milk yield and mean relative humidity is -0.77593. Therefore, the correlation coefficient is significant at the level of 0.01. Because 0.5 ≤ | r | < 0.8, the relative coefficient indicates that there is a moderate linear correlation between monthly milk yield and monthly mean relative humidity. As can be seen from Figure 4, the maximum value of monthly milk yield appeared in October 2014, 147 million kgMS, corresponding to the relative humidity of 79.4%. The minimum value of milk yield is 6.3 million kgMS, and the corresponding monthly relative humidity is 90.8%.

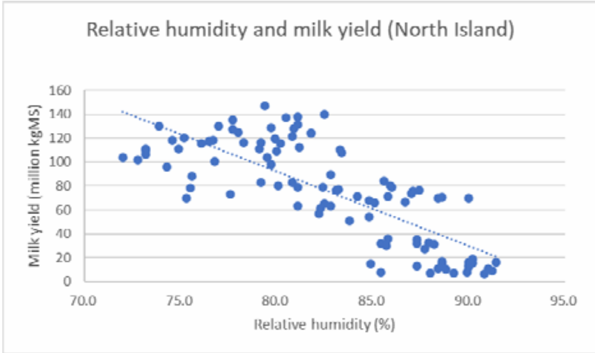

Figure 4 Monthly relative humidity and milk yield (North Island)

Monthly milk yield and total monthly precipitation

The correlation coefficient between monthly milk yield and total monthly precipitation is -0.3269. When n is equal to 99, and alpha is 0.01, the critical value of correlation coefficient significance is 0.25522. Therefore, the correlation coefficient is significant at the level of 0.01. Because 0.3 ≤ | r | < 0.5, the correlation coefficient indicates that the monthly milk yield and the total monthly rainfall in the North Island have a moderate to low linear correlation. It can be seen from Figure 5, the maximum milk yield of 147 million kgMS corresponds to the total monthly precipitation of 69.4 mm. The minimum value of milk production is 6.3 million kgMS, and the total monthly rainfall is 109.8 mm.

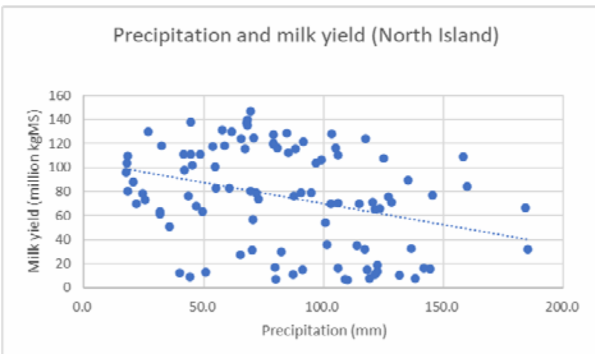

Figure 5 Monthly total precipitation and milk yield (North Island)

Monthly milk yield and monthly THI

The correlation coefficient between monthly milk yield and monthly THI is +0.461595. When n is equal to 99, and alpha is 0.01, the critical value of correlation coefficient significance is 0.25522. Therefore, the correlation coefficient is significant at the level of 0.01. Because $0.3 \leq | r | < 0.5$, the correlation coefficient indicates that the monthly milk yield and the monthly THI in the North Island have a moderate to low linear correlation. As can be seen from Figure 6, the maximum milk yield of 147 million kgMS corresponds to a monthly THI of 55.2. The minimum value of milk production is 6.3 million kgMS, and the monthly THI is 49.9 mm.

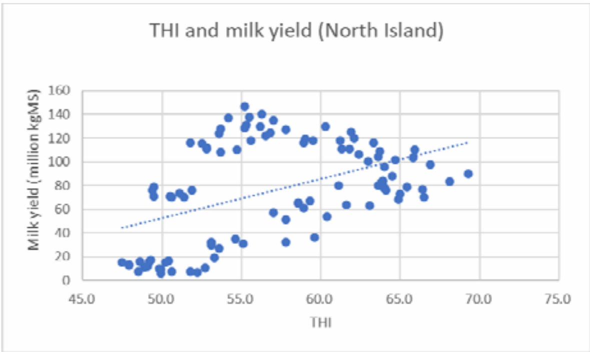

Figure 6 Monthly mean THI and milk yield (North Island)

Monthly milk yield with time in North Island

From the Figure 7 of monthly milk yield with time in North Island, it can be seen that the monthly milk yield changes periodically. The milk yield was the lowest in June and then increased rapidly, reaching the highest in October. After that, milk yield gradually decreased. The highest monthly milk yield was 147 million kgMS in October 2013. The minimum monthly milk yield was 6.3 million kgMS in July 2013.

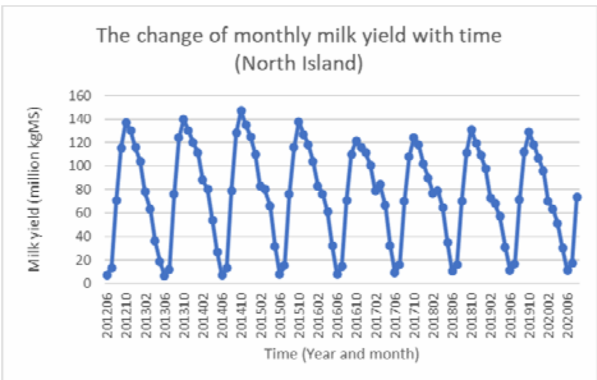

Figure 7 Milk yield (North Island)

Mean monthly milk yield

Figure 8 shows the mean monthly milk yield in the recent 9 years. As can be seen from the figure, the lowest mean milk yield is 9.4 million kgMS in June. The monthly mean milk yield in October is the highest, reaching 133.4 million kgMS. The mean milk yield in November reaches 124.2 million kgMS, which is the second-highest. The mean milk yield in September and December is 115.6 and 113.4 million kgMS, respectively.

After that, the mean milk yield in January reaches 101.6 million kgMS. The five months from September to January are the most important milk-producing months. The milk yield in these five months accounted for 64% of the total milk yield in the whole year.

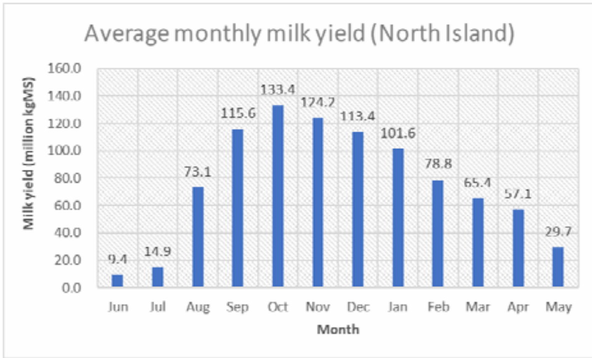

Figure 8 Monthly meanmilk yield (North Island)

Regression equation North Island

In North Island, monthly mean temperature, monthly extreme maximum temperature, monthly extreme minimum temperature, monthly mean relative humidity, and monthly mean THI are selected as independent variables to predict the monthly milk yield.

The R square is 0.752483, which indicates that the interpretation ability of the model is good. Suppose: the equation has no linear relationship. Due to significance f (1.04E-26) < 0.01, the hypothesis is rejected, and the equation is considered to be linear. The equation passes the F test. In addition, if $\alpha = 0$, it can be seen that P (2.24E-06) < 0.01, which means that α has passed the t-test; similarly, the P-values of $\beta 1$, $\beta 2$, $\beta 3$, $\beta 4$ and $\beta 5$ are 2.32E-09, 0.003697, 0.043824, 2.58E-20 and 1.45E-09 respectively. Therefore, $\beta 1$, $\beta 2$, $\beta 3$, $\beta 4$, $\beta 5$ all pass t-test. The final regression equation is as follows:

$$Y = -2408.71 - 148.286X1 - 6.35699X2 + 4.018059X3 - 6.95336X4 + 92.17441X5$$

Where:
Y: monthly milk yield.
X1: monthly mean temperature.
X2: monthly extreme maximum temperature.
X3: monthly extreme minimum temperature.
X4: monthly mean relative humidity.
X5: monthly mean THI.

South Island

Monthly milk yield and monthly mean temperature

When n is equal to 99, and alpha is 0.01, the correlation coefficient significance's critical value is 0.25522. The correlation coefficient between monthly milk yield and monthly mean temperature is +0.730267. Therefore, the correlation coefficient is significant at the level of 0.01. Because 0.5 ≤ | r | < 0.8, the correlation coefficient indicates that there is a moderate linear correlation between the monthly milk yield and the monthly mean temperature. It can be seen from Figure 9, the maximum value of monthly milk yield appeared in October 2018, which was 89 million kgMS, corresponding to the monthly mean temperature of 11.9 ˚C. The minimum value of monthly milk yield appeared in July 2016, which was 1.4 million kgMS, corresponding to the monthly mean temperature of 7.2 ˚C.

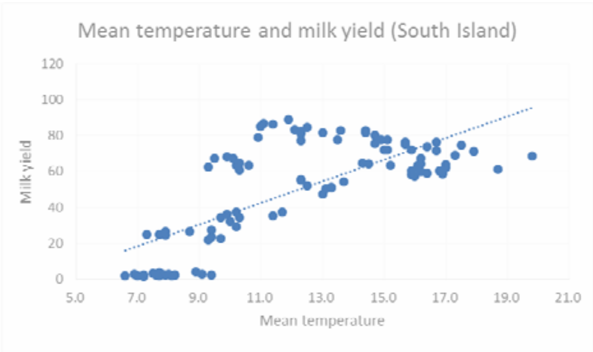

Figure 9 Monthly mean temperature and milk yield (South Island)

Monthly milk yield and monthly extreme maximum temperature

The correlation coefficient of monthly milk yield and monthly extreme maximum temperature is +0.76433. When n is equal to 99, and alpha is 0.01, the critical value of correlation coefficient significance is 0.25522. Therefore, the correlation coefficient is significant at the level of 0.01. Because 0.5 ≤| r | < 0.8, the correlation coefficient shows a moderate linear correlation between monthly milk yield and monthly extreme maximum temperature. As can be seen from Figure 10, the maximum monthly milk yield of 89 million kgMS corresponds to the extreme maximum temperature of 21.1 ˚C. The minimum value of milk yield is 1.4 million kgMS, and the corresponding extreme maximum temperature is 16.7 ˚C.

Monthly milk yield and monthly extreme minimum temperature

The correlation coefficient between monthly milk yield and monthly extreme minimum temperature is +0.724323. Because 0.5 ≤| r | < 0.8, the correlation coefficient indicates that there is a moderate linear correlation between the monthly milk yield and the monthly extreme minimum temperature. When n is equal to 99, and alpha is 0.01, the critical value of relative coefficient significance is 0.25522. Therefore, the relative coefficient is significant at the level of 0.01. It can be seen from Figure 11, the maximum milk yield is 89 million kgMS, and the corresponding extreme minimum temperature is 1.2 ˚C. The minimum value of milk yield is 1.4 million kgMS, and the corresponding extreme minimum temperature is –2 ˚C.

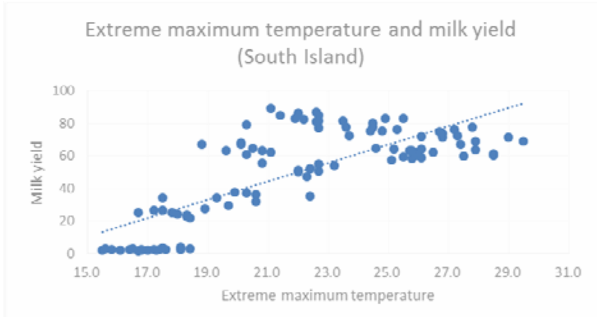

Figure 10 Monthly extreme maximum temperature and milk yield (South Island)

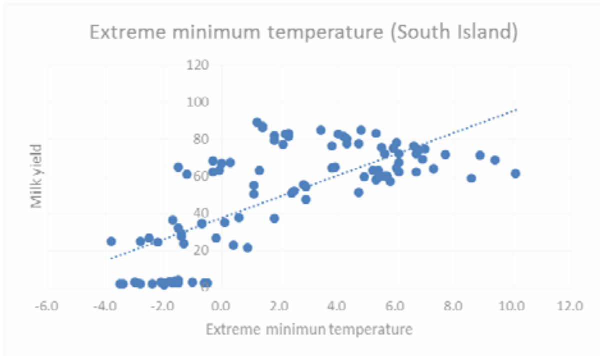

Figure 11 Monthly extreme minimum temperature and milk yield (South Island)

Monthly milk yield and monthly relative humidity

When n is equal to 99, and alpha is 0.01, the critical value of correlation coefficient significance is 0.25522. The correlation coefficient between monthly milk yield and monthly mean relative humidity is -0.74392. Therefore, the correlation coefficient is significant at the level of 0.01. Because 0.5 ≤ | r | < 0.8, the correlation coefficient indicates that there is a moderate linear correlation between monthly milk yield and monthly mean relative humidity. As can be seen from Figure 12, the maximum value of monthly milk yield appeared in October 2018, with the corresponding relative humidity of 82.1%. The minimum value of monthly milk yield is 1.4 million kgMS, and the corresponding monthly mean relative humidity is 84.6%.

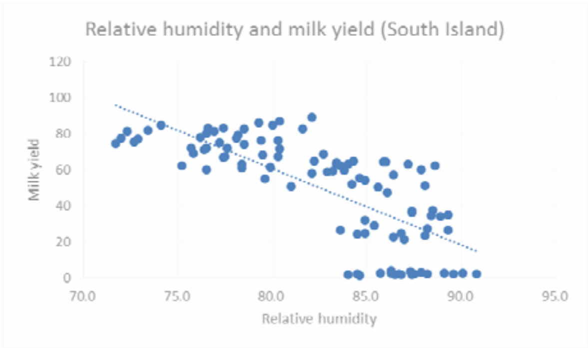

Figure 12 Monthly relative humidity and milk yield (South Island)

Monthly milk yield and total monthly precipitation

The correlation coefficient between monthly milk yield and total monthly precipitation is -0.008824. When n is equal to 99, and alpha is 0.01, the critical value of correlation coefficient significance is 0.25522. Therefore, the correlation coefficient is not significant at the level of 0.01. It can be seen from Figure 13, the maximum milk yield of 89 million kgMS corresponds to the total monthly precipitation of 108.8 mm. The minimum value of milk yield of 1.4 million kgMS corresponds to the total monthly rainfall of 151.9 mm.

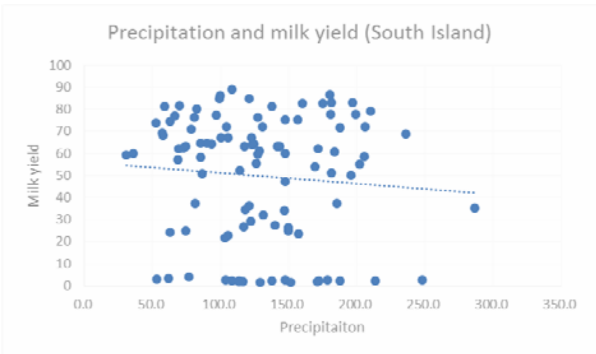

Figure 13 Monthly total precipitation and milk yield (South Island)

Monthly milk yield and THI

When n is equal to 99, and alpha is 0.01, the critical value of correlation coefficient significance is 0.25522. The correlation coefficient between monthly milk yield and mean monthly THI is +0.743912. Therefore, the correlation coefficient is significant at the level of 0.01. Because $0.5 \leq | r | < 0.8$, the correlation coefficient indicates that the monthly milk yield and the monthly average THI in the North Island have a moderate linear correlation. As can be seen from Figure 14, the maximum milk yield of 89 million kgMS corresponds to the monthly mean THI of 53.9. The minimum milk yield of 1.4 million kgMS corresponds to the monthly mean THI of 46.1.

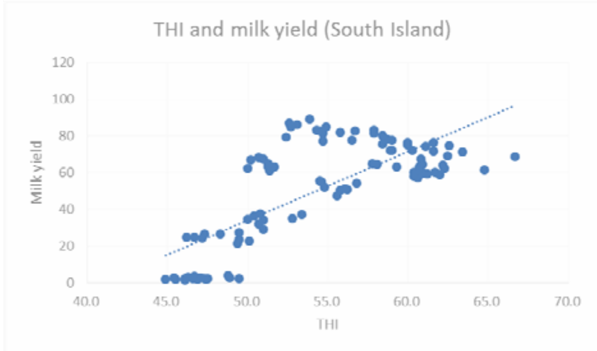

Figure 14 Monthly mean THI and milk yield (South Island)

Monthly milk yield with time in South Island

It can be seen from the figure of South Island monthly milk yield with the time that the monthly milk yield changes periodically. The milk yield is the lowest in July, then increased rapidly, and reaches the highest in October. After that, milk yield gradually decreases. The highest monthly milk yield was 89 million kgMS in October 2018. The minimum monthly milk yield was 1.4 million kgMS in July 2016.

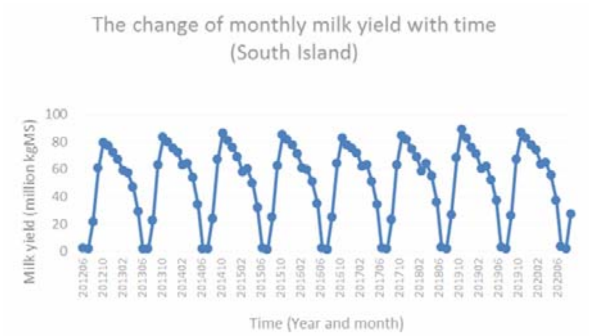

Figure 15 Milk yield (South Island)

Mean monthly milk yield

Figure 16 shows the monthly mean milk yield of South Island in the recent 9 years. As can be seen from the figure, the lowest mean milk yield in July is 1.7 million kgMS. The average monthly milk yield in June is 2.6 million kgMS, which is a sub low point. The monthly average milk yield in October is the highest, reaching 84.4 million kgMS. The average milk yield in November reaches 80.5 million kgMS, which is the second-highest. The average milk yield in December and January are 75.5 and 70.6 million kgMS, respectively. The average monthly milk yield in September, February, and March is between 60 and 65 kgMS. The four months from October to January are the most important milk-producing months in the South Island. The milk yield in these four months accounts for 50.1% of the total milk yield in South Island.

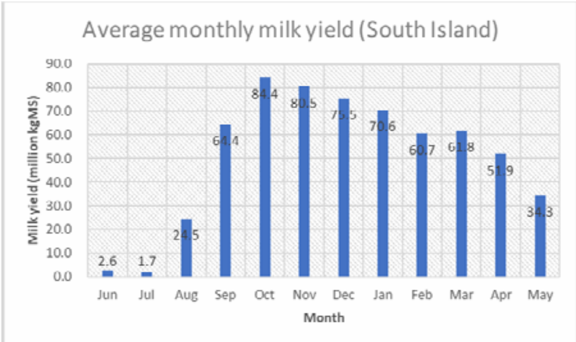

Figure 16 Monthly mean milk yield (South Island)

Regression equation South Island

In South Island, monthly mean temperature, monthly mean relative humidity, and monthly mean THI are selected as independent variables to predict the monthly milk yield. R square is equal to 0.833026007, which indicates that the model has good explanatory power. Suppose: the equation has no linear correlation. The significance f is equal to 8.53592E-37, which is less than 0.01. So the hypothesis is rejected, and the equation is linear. The equation passes the F test. In addition, if: α= 0, it can be seen that P (7.91596E-09) < 0.01, and reject the hypothesis, indicating that α has passed the t-test; similarly, the P values of β1, β2, and β3 are 6.89885E-10, 3.47289E-08, and 1.69635E-10, respectively. Therefore, β1, β2, and β3 all pass the t-test. The final regression equation is:

$$Y= - 1917.07 - 94.6968X1 - 1.85406X2 + 60.35103X3$$

Where:

Y: monthly milk yield.

X1: monthly mean temperature.

X2: monthly mean relative humidity.

X3: monthly mean THI.

North Island

The correlation coefficients of monthly milk yield and monthly mean temperature, monthly extreme maximum temperature, monthly extreme minimum temperature, and monthly mean THI are all positive, and all of them are moderate to low degree correlation. The absolute values of these correlation coefficients are all above 0.45. The correlation coefficient between monthly milk yield and total monthly rainfall is -0.3269. The correlation coefficient between milk yield and monthly mean relative humidity is a negative and moderate correlation. The correlation coefficient between monthly milk yield and monthly mean relative humidity is the highest, and the correlation coefficient with monthly total rainfall is the lowest. Bouyeh *et al.* (2017) studied the impact of climate on productive performances of ostrich. The results showed that the ostrich would have a better performance under hot and dry and mild and humid climates as compared to Alpine climate.

Mean monthly temperature

In the North Island, the monthly mean temperature affects milk yield. As shown in Figure 1, the monthly mean temperature corresponding to the maximum monthly milk yield is 12.7 ˚C. In the recent 9 years, the monthly mean temperature of the top six months of milk yield is in the range of 12.1-13.8 ˚C. When the monthly mean temperature deviates from 12.7 ˚C, the milk yield decreases. The results show that the monthly mean temperature affects the monthly milk yield. With the background of climate warming, the monthly mean temperature rise in summer has a negative impact on milk yield, while the monthly mean temperature rise in winter has a positive effect on milk yield. However, from the point of view of the total milk yield of the whole year, the rise of temperature has a totally negative impact on the milk yield. This accepts the hypothesis (H2) that monthly mean temperature has an effect on milk yield in New Zealand. At the same time, in North Island, the decrease of summer milk yield with the increase of mean temperature is consistent with other authors' opinions previously quoted. If the temperature exceeds the normal range, the milk yield will decrease (Balhara *et al.* 2001; Mote *et al.* 2016; Barash *et al.* 2001; Veissier *et al.* 2018; Herbut *et al.* 2018; Hristov *et al.* 2017; Dunshea *et al.* 2019).

Monthly extreme maximum temperature

Monthly extreme maximum temperature affects milk yield. As shown in Figure 2, the monthly extreme maximum temperature corresponding to the maximum monthly milk yield value is 22 ˚C. The extreme maximum temperature corresponding to the top six months of milk yield is 20.3-22.1 ˚C. When the monthly extreme maximum temperature exceeds 22 ˚C, milk yield decreases with the increase of extreme maximum temperature. It indicates that the extreme maximum temperature affects the milk yield. This may be due to the fact that the mechanism of the influence of the extreme maximum temperature on the milk yield is similar to that of the mean temperature. That approves that the hypothesis (H2) that monthly extreme maximum temperature affects milk yield is correct.

Monthly extreme minimum temperature

In North Island, the monthly extreme minimum temperature also affects the monthly milk yield. As shown in Figure 3, the monthly extreme minimum temperature corresponding to the maximum monthly milk yield is 1.1 ˚C. The monthly extreme minimum temperature corresponding to the top six months of milk yield is in the range of 0.1-3.7 ˚C. When the monthly extreme minimum temperature exceeds 1.1 ˚C, the monthly milk yield decreases with the extreme minimum temperature increase. The possible mechanism is consistent with the effect of monthly mean temperature on milk yield. It also confirms the hypothesis (H2) that monthly extreme minimum temperature has an effect on milk yield.

Monthly mean relative humidity

The monthly mean relative humidity also affects the monthly milk yield. As shown in Figure 4, the monthly mean relative humidity corresponding to the maximum monthly milk yield in North Island is 79.4%. The monthly mean relative humidity of the top five months of milk yield is from 77.7% to 82.5%. When the monthly relative humidity is greater than 80%, the milk yield decreases. It shows that the monthly mean relative humidity affects the monthly milk yield. The correlation coefficient between the two factors is negative. This is consistent with the views of Sae-tiao *et al*. (2017). Some scholars argue that there is a negative correlation between relative humidity and milk yield (Sae-tiao *et al*. 2017). It also confirms the hypothesis (H3) that relative humidity affects milk yield in New Zealand.

Total monthly rainfall

In the North Island, total monthly rainfall also affects milk yield. As shown in Figure 5, the monthly total rainfall corresponding to the maximum monthly milk yield is 69.4 mm. When the total rainfall exceeds 69.4 mm, the monthly milk yield decreases significantly. The possible mechanism is that the rainfall affects the growth of grass, and the quality of grass directly affects the milk yield. Rainfall can directly affect the growth of forage and indirectly affect the milk yield of dairy cows (Tata *et al*. 2012; Sloat *et al*. 2018). In addition, the correlation coefficient between total monthly rainfall and monthly milk yield is negative, which is consistent with the view of Stull *et al*. (2008). There is a negative correlation between the total monthly precipitation and milk yield on the test day. This also confirms the hypothesis (H5) that the total monthly rainfall affects milk yield in New Zealand.

Monthly mean THI

Monthly mean THI affects milk yield. As shown in Figure 6, the monthly mean THI corresponding to the maximum monthly milk yield in North Island is 55.2. The monthly mean THI of the top five months of milk yield is from 54.2 to 57. When the THI is greater than 55.2, the monthly milk yield decreases with the increase of THI. It is consistent with the effect of THI on milk yield mentioned in the literature review. The increase of ambient temperature and humidity makes intakes of dairy cows decrease and total milk yield decrease (Kekana *et al*. 2018; Ali, 2016; Das *et al*. 2016; Marami Milani, 2016; Marami Milani *et al*. 2016; Mote *et al*. 2016; Bekele, 2017; Hill and wall, 2017; Wildridge *et al*. 2018; Zaretamami *et al*. 2018; Mylostyvyi and Chernenko, 2019). It also shows that the hypothesis (H1) that THI affects milk yield in New Zealand is correct. The maximum value of THI in the North Island of New Zealand is 69.3, which is lower than the critical value of heat stress of 72. This indicates that dairy cows in the North Island of New Zealand have not been affected by high THI. However, due to strong solar radiation in summer and global warming, the New Zealand dairy industry needs to take measures to deal with the heat stress of dairy cows in summer.

Periodic changes of monthly milk yield

It can be seen from Figures 7 and 8 that the monthly milk yield of the North Island of New Zealand changes periodically with time. The milk yield of October is the highest, and that of June is the lowest. It shows that the monthly milk yield decreases with the increase in temperature after October. It is also related to the maturity of forage in October, which reflects the influence of climate on forage growth and milk yield of dairy cows. In addition, in order to improve milk yield, New Zealand cows are mated in autumn and winter. This is consistent with the previous literature. The milk yield of cows conceived in winter is higher than that in summer (Pinedo and De Vries, 2017).

Impact of climate change on milk yield

The annual mean temperature of North Island in recent eight years was fluctuating and rising, while the annual milk yield was rising first and then decreasing. Fonterra makes the milk production cycle year from June of a year to May of the next year. So the annual mean temperature corresponding to this study is also from June of the previous year to May of the second year. For example, the annual mean temperature in 2013 was the average temperature from June 2012 to May 2013. Gholami *et al*. (2020) conducted an experiment to evaluate the effects of stocking density and climate region on performance, immunity, carcass characteristics, blood plasma, and economic parameters of the chickens. The results showed that the high environmental temperature weakens the immune system of the birds. The current study is measuring the effect of climate on milk yield only. However, getting more milk yield needs a strong immune system of the animals.

As shown in Figure 17, the annual mean temperature reached a maximum of 14.6 degrees Celsius in 2018. The annual mean temperature in 2019 was a sub high. 2018 and 2019 were the two years with the largest annual mean temperature, and the corresponding annual milk yield was the lowest two years except 2013 and 2020, which was only slightly higher than that in 2013 and 2020. Annual milk yield reached a maximum at an annual mean temperature of 13.8 ˚C. The annual milk yield of North Island decreased with the increase of annual mean when temperature above 13.8 ˚C. When the annual mean temperature was lower than 13.8 ˚C, the milk yield increased with the increase of the annual mean temperature. In the past eight years, the annual mean temperature had reached 14 ˚C, which shows that in the context of climate warming, Fonterra needs to take measures to alleviate the negative impact of rising temperature on milk yield.

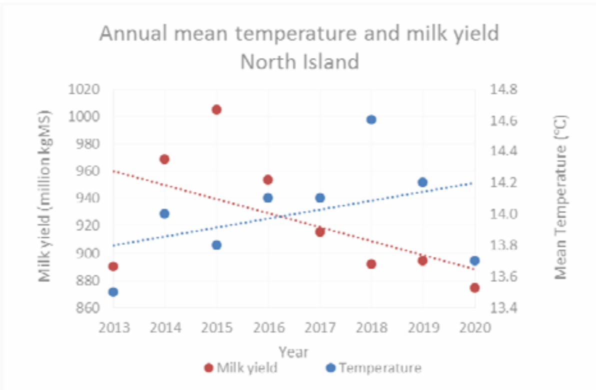

Figure 17 Annual mean temperature and milk yield

South Island

The correlation coefficients between monthly milk yield and monthly mean temperature, monthly extreme maximum temperature, monthly extreme minimum temperature, and monthly mean THI are all positive. All are greater than 0.72, indicating a moderate correlation. The correlation coefficient between milk yield and monthly mean relative humidity is -0.743912, which is a moderate correlation. The correlation coefficient between monthly total rainfall and monthly milk yield is -0.08824, which does not pass the significance test. Therefore, the correlation coefficient between monthly milk yield and monthly extreme maximum temperature in South Island is the highest, reaching + 0.76433.

Mean monthly temperature

In the South Island of New Zealand, the mean monthly temperature affects milk yield. As shown in Figure 9, the monthly mean temperature corresponding to the maximum month milk yield was 11.9 ˚C. In the recent 9 years, the monthly mean temperature of the top five months of milk yield was in the range of 11-12.5 ˚C. When the mean monthly temperature exceeded 11.9, the milk yield decreased. The results show that the monthly mean temperature affects the monthly milk yield. Under the background of climate warming, the results are consistent with that of the North Island. The increase of mean temperature in summer has a negative impact on milk yield in South Island, while the increase of monthly mean temperature in winter has a positive effect on milk yield. However, from the point of view of the total milk yield of the whole year, the rise of temperature has a totally positive impact on the milk yield. It proves the hypothesis (H2) that mean temperature has an effect on milk yield in New Zealand.

Monthly extreme maximum temperature

The extreme maximum temperature affects the monthly milk yield. As shown in Figure 10, the monthly extreme maximum temperature corresponding to the maximum monthly milk yield was 21.1˚C. The monthly extreme maximum temperature corresponding to the top six months of milk yield was between 21.1 and 22.7. The result was the same as that in North Island. This may be due to the fact that the influence mechanism of monthly extreme maximum temperature on milk production is similar to that of monthly mean temperature. It proves that the hypothesis (H2) that extreme maximum temperature affects milk yield in New Zealand is correct.

Monthly extreme minimum temperature

In South Island, the monthly extreme minimum temperature also affects the monthly milk yield. As shown in Figure 11, the monthly extreme minimum temperature corresponding to the maximum monthly milk yield was 1.2 degrees Celsius. The monthly extreme minimum temperatures corresponding to the top three months of milk yield were between 1.2 and 1.4 degrees Celsius. When the monthly extreme minimum temperature exceeded 1.2 ˚C, the milk yield decreased. The results are consistent with that of the North Island. The possible mechanism is consistent with the effect of mean temperature on the monthly milk yield. It also confirms the hypothesis (H2) that monthly extreme minimum temperature has an effect on milk yield.

Monthly mean relative humidity

The monthly mean relative humidity also affects the milk yield. As shown in Figure 12, the monthly mean relative humidity corresponding to the maximum value of monthly milk yield in South Island was 82.1%. The monthly mean relative humidity of the top 8 milk yield months was between 74.1% and 82.1%. When the relative humidity was greater than 82.1%, the milk yield decreased. This shows that the monthly mean relative humidity affects the monthly milk yield. The correlation coefficient between the two factors was negative, which is consistent with the situation in North Island. At the same time, this is consistent with the previously mentioned view by Sae-tiao *et al.* (2017) that there is a negative correlation between relative humidity and milk yield. It also supports the hypothesis (H3) that relative humidity affects milk yield in New Zealand.

Total monthly rainfall

The correlation coefficient between the total monthly rainfall and the monthly milk yield did not pass the significance test. However, in North Island, the correlation coefficient between the total monthly rainfall and the monthly milk yield was negative.

Monthly mean THI

The monthly mean THI affects the monthly milk yield. As shown in Figure 14, the monthly mean THI corresponding to the maximum monthly milk yield in the South Island was 53.9. The monthly mean THI of the top five months of month milk yield was between 52.6 and 54.9. When the THI was greater than 53.9, the monthly milk yield decreased with the THI. This result is consistent with that of North Island. It is also consistent with the effect of THI on milk yield mentioned in the literature review. The increase of ambient temperature and humidity makes intake of dairy cows decrease and total milk yield decrease (Kekana *et al.* 2018; Hill and Wall, 2015; Ali, 2016; Das *et al.* 2016; Marami Milani, 2016; Marami Milani *et al.* 2016; Mote *et al.* 2016; Bekele, 2017; Wildridge *et al.* 2018; Zare-Tamami *et al.* 2018; Mylostyvyi and Chernenko, 2019). It also shows that the hypothesis (H1) that THI affects milk yield in New Zealand is accepted. The maximum value of THI in the South Island of New Zealand was 66.7, which was lower than the critical value of heat stress (72). This indicates that the dairy cows in the South Island of New Zealand have not been affected by high THI.

Periodic changes of monthly milk yield

It can be seen from Figures 15 and 16 that the monthly milk yield of the South Island of New Zealand changed periodically with time. The highest milk yield was in October, and the lowest was in July. It showed that the monthly milk yield decreased with the increase in temperature after October. In addition, October is the mature period of forage. The milk yield reached a peak in October, which reflected the influence of climate on forage growth and milk yield of dairy cows. Furthermore, in order to increase milk yield, South Island cows are mated in autumn and winter. This is the same as that in North Island. It is also consistent with the previous literature. The milk yield of cows conceived in winter is higher than that in summer (Pinedo and De Vries, 2017).

Impact of climate change on milk yield South Island

As shown in Figure 18, the annual milk yield in South Island showed a steady upward trend, while the annual mean temperature in the South Island showed a fluctuating upward trend. This indicates that with climate warming, milk yield in South Island increased. The temperature of South Island was the most suitable temperature for lactation. However, when the temperature continues to rise, the same phenomenon will appear: the too high temperature will lead to a decrease in milk yield. In the future, a small increase in temperature is conducive to the increase of annual milk yield in South Island. However, measures should be taken to alleviate the negative impact of high temperature on milk yield in summer.

CONCLUSION

In North Island, the monthly milk yield changed periodically with time. The milk yield was the lowest in June and the highest in October. The monthly milk yield was positively correlated with monthly mean temperature, monthly extreme maximum temperature, monthly extreme minimum temperature, and monthly mean THI. The correlation coefficient was between +0.45087 and +0.46765. The correlation coefficient between monthly milk yield and monthly mean relative humidity was -0.7759. The correlation coefficient between monthly milk yield and total monthly rainfall was -0.3269. When the monthly mean temperature of North Island exceeded 12.7 ˚C, the monthly milk yield decreased with the increase of monthly mean temperature. When the relative humidity was greater than 79.4%, the monthly milk yield decreased with the increase of relative humidity. However, when the total month precipitation exceeded 69.4mm, the monthly milk yield decreased with the increase of total month precipitation. It can be seen in Figure 6, the monthly mean THI corresponding to the maximum value of monthly milk yield was 55.2. When the THI exceeded this value, the monthly milk yield decreased with the increase of THI. As shown in Figure 17, when the annual mean temperature exceeded 13.8 ˚C, the annual milk yield also decreased with the increase of the annual mean temperature. In the past eight years, the annual mean temperature had reached 14 ˚C. This means the annual milk yield will decrease with the increase of temperature. Therefore, Fonterra needs to take immediate measures to deal with the negative impact of climate warming. In addition, the following regression equation is established:

$$Y = -2408.71 - 148.286X1 - 6.35699X2 + 4.018059X3 - 6.95336X4 + 92.17441X5$$

Where:
Y: monthly milk yield.
X1: monthly mean temperature.
X2: monthly extreme maximum temperature.

X3: monthly extreme minimum temperature.
X4: monthly mean relative humidity.
X5: monthly mean THI.

This equation can help Fonterra to predict the future monthly milk yield. In South Island, the monthly milk yield also shows a cyclical change with time. The maximum monthly milk yield appeared in October. This is consistent with North Island. The minimum monthly milk yield appeared in July. The correlation coefficients between monthly milk yield and monthly mean temperature, monthly extreme maximum temperature, monthly extreme minimum temperature, and monthly mean THI were all positive, which were all greater than 0.72. The correlation coefficient between monthly milk yield and monthly relative humidity was -0.743912. When the monthly mean temperature exceeded 11.9 ˚C, the monthly milk yield decreased with the increase of the monthly mean temperature. When the monthly mean relative humidity was greater than 82.1%, the monthly milk yield decreased with the increase of relative humidity. The monthly mean THI corresponding to the maximum value of monthly milk yield was 53.9. When the THI exceeded this value, the monthly milk yield decreased with the increase of THI. In recent 8 years, the annual milk yield increased with the increase of temperature. In the short term, a small range of temperature rise is conducive to the increase of milk yield in South Island. However, South Island needs to deal with the negative impact of high temperature on milk yield in summer. At the same time, when the temperature continues to rise, it is expected that the same phenomenon will appear as in North Island; that is, when the mean temperature exceeds a certain threshold, the milk yield will decrease with the continuous rise of temperature. South Island still has time to take measures ahead of time to deal with the impact of climate warming on milk yield.

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