Doctoral Dissertation

Application of Bio-Climatic Indicators for Tea Cultivation in Uji Area –Drawing from the Experience of Winegrape Terroirs-

（宇治地域の茶栽培へのバイオ･クライマテック指標の応用　～ワインブドウのテロワールの知見から～）

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Doctoral Program in Policy Science
Graduate School of Policy Science
Ritsumeikan University

Fitrio Ashardiono

Abstract of Doctoral Dissertation

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In regards to the on-going climatic changes, the agriculture industry is among those which are directly affected by changing climatic behavior. Among the agriculture industries, tea and winegrape cultivation possess similar traits, especially on their sensitivity towards changes in the micro-climatic condition. There are many indications of similar elements between winegrape terroirs with the tea cultivation in Japan, especially Uji Area. Whereas in the cultivation process, the importance of natural environmental conditions and utilized agriculture practices are highly regarded as the important elements which affect the product characteristics. Changes in climatic conditions, especially air temperature will have a direct effect on the growth cycle of tea plant, which are especially crucial during leaf bud break to harvest period. In this research it was found that changes in the climatic condition have overwhelm other elements in the terroir concept and have been directly affecting both the natural environmental elements and agriculture practices. The focus of this research is application of bio-climatic indicators based from the terroir concept developed from the winegrape cultivation. The terroir concept in this study is elaborated in to two elements: natural environmental elements and agriculture practices elements (traditional agriculture knowledge), whereas important bio-climatic

indicators were identified through series of micro-climatic data monitoring and recordings, complemented with social surveys and observations. For the tea growers to be able to utilize the bio-climatic indicators such as Heliothermal Index (HI), Cool Night Index (CI), Humidity Index (Hum-I) and Warm Day Index (WI), these indicators need to be reformulated and recalculated based on the phenological process of tea cultivation. The calculated bio-climatic indicator values would provide more input and information to the tea growers, whereas HI is useful for selection of land as well as cultivars for tea cultivation. CI and Hum-I would be useful to predict optimal cultivation intervention timing such as time to fertilize, utilize leaf cover and frost protection system. WI could be utilized to formulate effective cultivation intervention types such as selection of leaf covering level and types of soil fertilizers. Through observation of the bio-climatic indicators moving averages values, decision on cultivation intervention timing and types could be made swiftly and effectively, thereby allowing them to better adapt with the changing climatic factor, as well as developing new intervention methods on tea cultivation process, to maintain and provide better value of tea productions. Bio-climatic indicators will be the basis for new tea cultivation knowledge which is explicit and transmittable among the tea growers, complementing the already existed implicit cultivation knowledge inherited from tea growers' family. From the combination of the two knowledge young and less experienced tea growers as successor would be able to quickly comprehend the mechanism of an important cultivation process, as well as understanding how the indicator values will affect the tea production quantity and quality. These would contribute to the socio-economic benefit of Uji Area, which ultimately ensuring the sustainability of Uji Area as a tea growing region. Application of terroir concept and bio-climatic indicators on tea cultivation industry in Uji Area would redefine the notion of Uji Tea, consequently the derived values from bio-climatic indicators calculations could be utilized to define the terroir boundaries of new Uji Tea definition.

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List of Abbreviations

AD	:	Anno Domini
BCI	:	Bio-Climatic Indicators
cb	:	Centibar
CI	:	Cool Night Index
DRQ	:	Detail Research Question
etc	:	et cetera
Ha	:	Hectare
HI	:	Heliothermal Index
Hum-I	:	Humidity Index
IPCC	:	Inter-Governmental Panel on Climate Change
Kg	:	Kilogram
m	:	Meter
mm	:	Millimeter
m/S	:	Meter per Second
RQ	:	Research Question
UNFCCC	:	United Nations Framework Convention of Climate Change
Viz	:	videlicet
WI	:	Warm Day Index
W/m^2	:	Watt per Square Meter

CHAPTER 1

RESEARCH INTRODUCTION

1.1 Research Background

The current rapid transformation in climatic conditions might not have directly affected our daily life yet, however new research findings have found that with the current transformation rate it is projected that these changes will undoubtedly affect our daily lives in the near future (IPCC, 2014). Anecdotal information from the agricultural sector have shown that it has becoming more difficult to predict changes in the weather patterns which immediately affect optimal times for agricultural interventions during the cultivation season. Changes in the weather pattern can be clearly observed as the timing of wet and dry seasons are slowly shifting from their usual periods. Excessively intense rainfall is often followed by prolonged drought. Increasing occurrences of extreme weather events, such as the number of days with abnormal temperatures have been occurring more often compared with the past years.

Based on the definition by the United Nations Framework Convention on Climate Change (UNFCCC) (1994), Climate Change means a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods. The adverse effect of climate change is defined as changes in the physical environment or biota resulting from climate changes which have significant deleterious effect on the composition, resilience or productivity of natural and managed ecosystems or on the operation of socio-economic systems or on human health and welfare (UNFCCC, 1994).

In regard to these climatic changes, the agriculture industry is among those which are directly affected by changing climatic behavior. Agricultural crops are grown and harvested seasonally in a specific period of climatic condition to obtain the desired optimum harvest quantity and quality. Some of the crops require a certain temperature range to grow and thus, climatic conditions directly affect harvest quality and quantity. Based on the Intergovernmental Panel on Climate Change (IPCC) (2007), climate change is expected to be manifest in increases in mean temperature, altered precipitation patterns, greater frequency of extremes, and increased climatic variability. These changes in the climatic behavior have directly affected harvest quality and quantity of agricultural crops, especially those which are very sensitive towards changes in the climatic condition such as winegrape and tea cultivation.

Among the agriculture industries, tea and winegrape cultivation are among those which are very sensitive towards climatic changes, especially at the micro climatic level where these changes will directly affect the quality of the cultivated products. While winegrape as a crop are not very crucial to human survival, the extraordinary sensitivity of the grape vine towards climate makes the industry a strong early-warning system for problems that all food crops may confront as climates continue to change (Jones & Webb, 2010). This statement is also true for the tea industry, as weather conditions greatly influenced tea yield as well as harvested tea quality (Wijeratne, 1996).

Changes in climatic conditions, especially air temperature will have a direct effect on the growth cycle of the tea plant, and are especially crucial during the bud break and flush harvest periods. Moreover high quality leaf can only be obtained from tea plants which are grown under a stable climatic conditions, as the formation of leaf fiber and growth are influenced heavily by the climatic conditions. The textures of tea leaf fibers plays a very important role on deciding the types of tea produced from the harvested leaves, whereas the leaves with smooth and soft fibers (fine leaves) are essential to produce high quality teas. Slightly fibrous leaf (medium leaves) and matured fibrous leaf (coarse leaves) are in general will be processed as a lower quality tea products. Climate change effect towards the cultivation of tea in general can be categorized into two types, which are:

1. Average temperature increase (warming of the climate) and;
2. Increasing occurrences of extreme weather events.

Tea cultivation possess similar traits with winegrape cultivation especially its sensitivity towards changes in the micro climatic condition, therefore through observation on how the changes affect tea plants, it would be an important reference for other agriculture cultivation process. Moreover because of its traits Wijeratne (1996) mentioned that increasing temperature and changing rainfall pattern is very harmful for the growth of the tea plants, which ultimately affects the quality and quantity of the final tea products.

The focus of this research is to develop a precise cultivation framework based on natural environment and traditional cultivation practices utilizing some of the concepts derived from winegrape cultivation as a method to adapt with the on-going climatic changes as well as to ensure the sustainability of the tea cultivation region from socio-economic perspectives. In this study it is proposed that the key to achieve this is through the development of bio-climatic indicators. These indicators show how within certain value ranges, the environmental elements can affect the plant phenology, viz: plant growth, harvest quantity and quality.

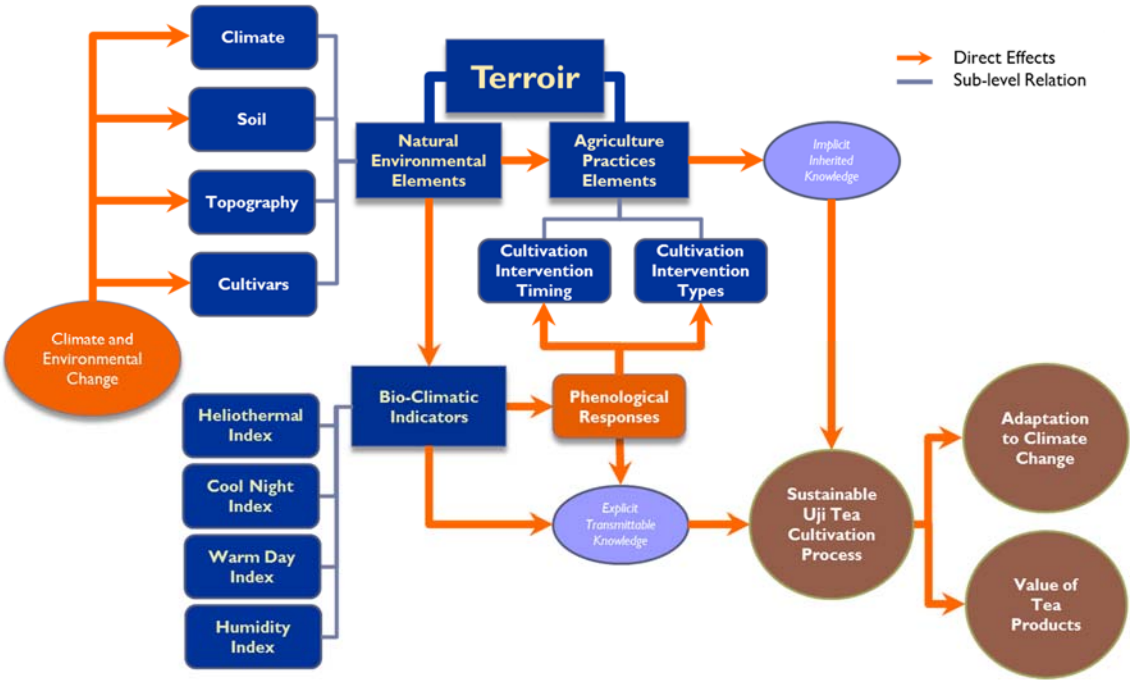


Figure 1.1 Research Framework

The research framework as shown in figure 1.1 will be utilizing the *Terroir Concept* derived from the wine grape cultivation tradition, in order to develop bio-climatic indicators to analyze the tea cultivation process. From the values of these bio-climatic indicators critical decisions related to cultivation interventions could be made effectively and optimally. As seen in several well-known tea growing regions, the local tea growers have been cultivating tea for hundreds of years for several generations. Clearly the tea growers in these areas have been able to fully incorporate the natural environmental factors of their area for cultivating tea products which are desirable for them. This is similar to winegrape growing regions where natural environmental factors are very important as they directly affect the character and quality of the wine products. These factors are further incorporated in the *Terroir Concept* (van Leeuwen and Seguin, 2006) where beside the natural environment, traditional cultivation practices which originated and developed in the region are also seen as crucial in defining the products characteristics, quality and quantity. Thus, the terroir concept is crucial to identify the changes that occurred in the region, especially with respect to the links between climatic conditions and tea production characteristics.

Rapid transformation of climate behavior has affected tea cultivation process, with evidence of increasing temperature as well as increasing occurrences of extreme weather events. A widespread observation shows that winegrapes harvest dates have advanced, especially in the last 10-30 years (de Orduna, 2010), while in the case of Japanese tea, the harvesting period has the tendency to become later than in previous years (Kyoto Prefecture Tea Industry Research, 2012). These issues coincidentally have been identified in Uji Area, which is the oldest and most famous tea growing region in Japan. From the preliminary findings it is most likely that the frequencies of abnormal climate events occurring in Uji Area will increase in the near future.

1.2 Research Objectives

As previously mentioned, this research theme focuses on climate change adaptation of the tea industry to ensure the sustainability of the cultivation region through product value addition. Currently the research consists of three main objectives which are:

1. Redefining terroir concept for Uji tea cultivation to identify important **terroir elements** in the cultivation process.
2. Developing **bio-climatic indicators** for Uji Tea cultivation to create explicit precision agriculture knowledge.
3. Developing cultivation intervention methods using bio-climatic indicators to

swiftly adapt with the ongoing climatic changes and ensure the **sustainability** of Uji Area as a tea producing region.

1.3 Research Significance

Historically terroir concept is incorporated in the winemaking process as a means of showing the strong relationship between wine products with the area and community where the product is produced. Gade (2004) noted that through the notion of terroir, it can be argued that the special quality of an agricultural product can be determined by the character of the place where the product comes. This research aims to identify and implement the terroir concept for tea cultivation, especially in Uji Area, where tea cultivation in the area has been conducted for at least 500 years.

There are many indications of similar elements between traditional "old world" winegrape cultivation with tea cultivation in Japan, whereas in the cultivation processes of both crops the importance of natural environmental elements is highly regarded. Winegrape growers as well as tea growers put in meticulously detailed interventions information the cultivation process, carefully utilizing the environmental elements to their advantage. With these similarities in the cultivation elements, utilization of terroir concept in the tea cultivation will add further value and optimize the cultivation process as well, thereby ensuring the sustainability of the area as a well-known tea growing region.

Implementation of the terroir concept in Uji Area would lead to the identification of important terroir elements, whereas understanding the interactions between these elements would provide further comprehension on how it affect the characteristic of the tea products. Based on the general terroir definition, the elements could be divided into two which are natural environment and agriculture practices, thereby with the current changes occurring in the climatic condition, to certain degree it would have affected the terroir elements.

Through the utilization of the terroir concept in the tea cultivation, new bio-climatic indicators would be able to be developed based from winegrape cultivation. The new indicators are optimized to further understand the phenological elements in the tea cultivation which will provide new insight for the tea growers. Bio-climatic indicators will be the basis for new tea cultivation knowledge which is explicit and transmittable among the tea growers to complement with the implicit cultivation knowledge which they have already inherited from inside their family.

Application of bio-climatic indicators in the tea cultivation would provide precision information to the tea growers and based from the values, new cultivation intervention methods would be able to be constructed. Through the application of these cultivation methods Uji Area tea growers would be able to cope and swiftly adapt with the changing climatic conditions as well as lead to the prediction of tea production quantity and quality.

The terroir concept developed from this research would be applicable to other agricultural crops too. Important bio-climatic indicators could be identified for each agricultural crop thereby contributing to the sustainability of the agricultural cultivation regions.

1.4 Research Questions

With the underlying research objectives, the accompanying research questions are as follows:

1. How do changes in the climate factors of the terroir elements impact the other

terroir elements of Uji Area tea cultivation?

2. How can we modify the bio-climatic indicators commonly used in winegrape terroir for utilization in Uji Area tea cultivation?
3. How do changes in bio-climatic indicators values signal cultivation interventions to overcome the impact of changing climate factors and enhance yield and value?

1.5 Research Hypothesis

In relation with the research objectives and research questions, several research hypothesis and detail research questions have been constructed, which are:

1. Changes in the climatic condition have overwhelm other elements in the terroir concept and have been directly affecting both the natural environmental elements and agriculture practices elements.
   - DRQ 1-1: How does climate change affect natural environmental elements?
   - DRQ 1-2: How does climate change affect agriculture practices elements?

2. Bio-Climatic Indicators commonly used in winegrape terroir have to be reformulate and calculated according to the tea cultivation process cycle whereas the modified indicators are Heliothermal Index, Cool Night Index and Humidity Index as a proxy for Dryness Index, as well as leading to the development of Warm Day Index derived from Cool Night Index.
   - DRQ 2-1: How to reformulate and calculate bio-climatic indicators for Uji tea cultivation process?
   - DRQ 2-2: How can the bio-climatic indicators value be used to predict the yield and value of the cultivated tea?

3. Bio-climatic indicators values would provide precision information to the tea growers whereas from these values, effective cultivation intervention types and optimal cultivation intervention timing could be conducted leading to the formulation of new cultivation intervention methods. These new intervention methods would allow the tea growers to swiftly adapt with the changing climatic factor as well maintaining and enhancing the yield and value of tea productions.
    - DRQ 3-1: How to utilize the bio-climatic indicators in cultivation intervention process?
    - DRQ 3-2: How do the tea growers swiftly adapt with the ongoing climatic changes?

1.6 Research Scope

This research is focused only on the analysis of the tea cultivation process especially on the first flush tea harvest conducted in Uji Area. Analyses include identification of important elements in the terroir framework which are natural environmental element and agriculture practices elements. This research will try to identify the correlation between bio-climatic indicators developed from this research with the tea production yield and values, as well as understanding the implication of the climatic changes towards the socio-economic conditions of tea growers in Uji Area.

CHAPTER 2

TERROIR OF UJI TEA

2.1 Uji Tea

Although the brand name of Uji Tea might not be a familiar name among most people, Japanese green tea is very popular among Japanese people and tea enthusiasts worldwide as it is regarded as a high quality tea with health benefit properties. Although there are many types of green tea in Japan, what is commonly known outside Japan would be *matcha* or *sencha*. In comparison with wine products, where the information label is printed on each wine bottle, unfortunately on most tea packages information about the location of the tea growing region is not available even for products which are sold domestically inside Japan. For the Japanese green tea enthusiast, teas which are cultivated and produced from Uji Area especially powdered green tea which known as *matcha*, is the benchmark of high quality tea in Japan.

There are three types of tea produced in Uji Area mainly consist of *tencha*, *gyokuro* and *sencha*. Most of these tea products use the same tea cultivars whereas the differences lies on the cultivation process. *Sencha* is the most popular green tea consumed in Japan, whereas this type of tea is grown fully under the sun. In contrast with *sencha* cultivation, *tencha* and *gyokuro* is grown under shade or covering for about 21 days before harvest. Depending on the period of covering the harvested tea leaves can be processed into *gyokuro* (less than 21 days of covering) or *tencha* (more than 21 days of covering).The latter is stone ground to become *matcha*.

Currently Uji Area is the oldest and most famous tea growing region in Japan, where according to historical archives, tea cultivation in the area began in 1191 AD (Kyoto Prefecture Government, 2011). Originally Uji Tea refers to tea products which are cultivated within the borders of Uji Area, and it is well known for its extraordinary quality as it only used to cater to the nobility. Because of its resource consuming cultivation methods, traditionally the tea produced in Uji Area is only available in a low volume, therefore in order to comply with the continuous high demand from consumers, the Ujicha Cooperative (京都府茶業組合) (2006), a wholesaler collective, defined Uji Tea as tea products which are grown in four prefectures: Kyoto, Nara, Shiga and Mie; and processed inside Kyoto Prefecture by a tea wholesaler based in Kyoto Prefecture.

2.1.1 History of Uji Tea

Based on Uji City historical archive (2010), the origin of tea cultivation in Japan started around the late 12th century and beginning of 13th century when a Zen monk Eisai brought back tea seeds from his journey to China. Some of this seeds then were given to priest Myoe Shonin which then he made a tea plantation in Uji because the land is ideal for tea cultivation. During the Muromachi Era Shogun Yoshimitsu Ashikaga established a tea plantation called "Uji Shichimeien" in Uji Area thus this became the foundation of what is widely known as Uji Tea. In the Age of Provincial Wars the shoguns enjoyed and became accustomed to tea drinking, and because of this the tea masters in Uji Area were requested to prepare high quality teas, thereby leading to Uji tea becoming increasingly valued in Japan.

Throughout history, teas produced in Uji Area are strongly related with *tencha*, from which *gyokuro* and *matcha* were later produced. *Tencha* was born when Hisashige

Kanbayashi, tea planter from Uji Area first shaded the tea plantations with covering materials which happened somewhere during the rule of Toyotomi Shogun Era. Since then throughout the history and traditions many tea producers and traders in Uji Area have worked steadily improving the tea-making techniques which have since then become the trademark of Uji Tea.

2.1.2 Location of Uji Area

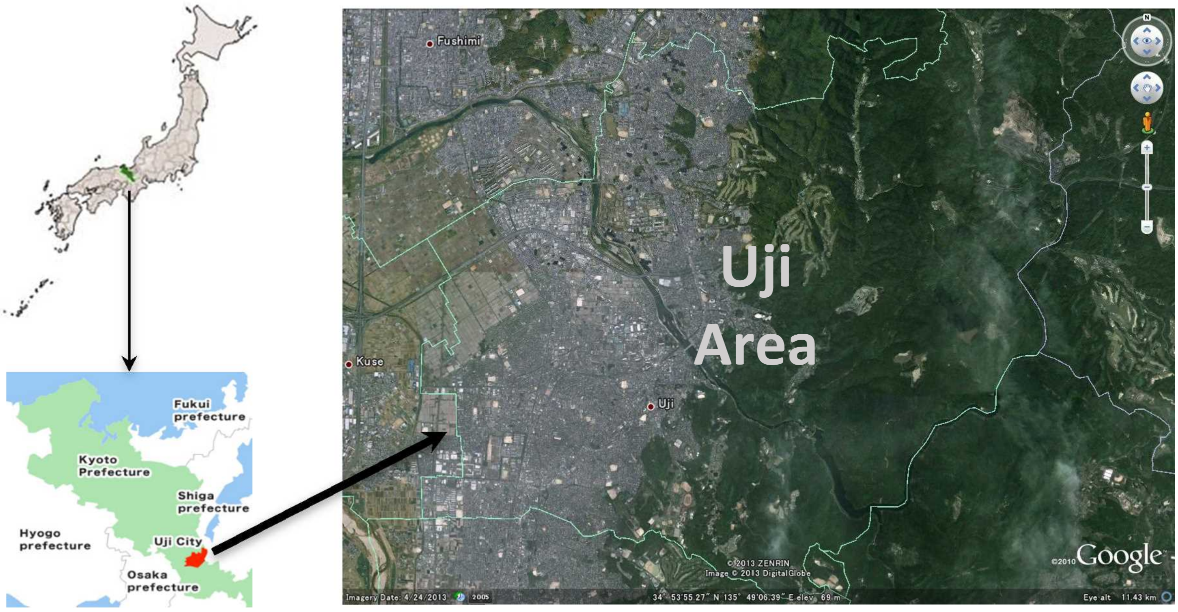
Uji Area or Uji City is situated in the south part of Kyoto Prefecture with a land area of 67.55 km^2. Although this area is famous for tea cultivation, currently there are only 113 active tea growers[1] and 21 registered tea plantations[2] inside Uji Area from the total population of 189,609 residents (Kyoto Prefecture Government, 2013). Uji Area topographical situation consist of river plains and flat lands with hills on the east and south part of the area.

Tea plantations are mostly located around river plains and on the hills area, whereas tea plantations from each locations produce tea with different characteristics. Tea characteristic from each locations are directly affected by the natural environmental conditions of each location. Through hundreds of years of observations on these natural environmental conditions, each tea grower has developed special techniques which allow the full exploitation of nature in producing their teas.

[1] Tea grower or「茶農家」in Japanese is defined as individual who is cultivating tea as a production crop, as a full time or part time profession on a tea plantation owned by themselves or by other tea growers.

[2] Tea Plantation or 「茶園」in Japanese is defined as patch of land dedicated for tea cultivation regardless of the size of the land area.

This combination of micro-climatic conditions and traditional tea cultivation techniques can become the foundations of Uji Tea *Terroir*, where these terroir elements are crucial and irreplaceable in Uji Tea cultivation as they are the building blocks of what characterizes Uji Tea.



(Source: Kyoto Prefecture Government, 2014; Google Earth, 2014)

Figure 2.1 Location of Uji Area

This research study identifies important terroir elements in a tea cultivation area which consist of Natural Environmental Elements and Agriculture Practices Elements (Traditional Agriculture Knowledge) in Uji Area (Ashardiono & Cassim, 2014). The sub elements of the former are: 1) Climate; 2) Soil; 3) Topography; 4) Cultivars; and sub elements of the agriculture practices elements are cultivation intervention types and timing. For generations tea farmers in Uji Area have been carefully utilizing these natural characteristics in the production of Uji Tea and have understand that different locations of tea plantation resulted in different characteristic of tea products. These characteristics emerge by taking advantages of soil type differences and topographical conditions, combined with a thorough selection of the planted cultivars.

Based on the Kyoto Prefecture Government (2014) data currently there are 81.6 Ha of tea plantations in total with actively producing tea plantations covering 80 Ha, which is comparatively small compared to other tea producing regions in Japan. In general tea growers in Uji Area are cultivating eleven tea cultivars, which are: 1) Uji Midori; 2) Kyomidori; 3) Yabukita; 4) Samidori; 5) Asahi; 6) Uji Hikari; 7) Ogura Midori; 8) Gokou; 9) Komakage; 10) Okumidori; 11) Houshun; and 12) Tenmyou. Among these twelve cultivars seven cultivars: Uji Midori, Kyomidori, Samidori, Asahi, Uji Hikari, Ogura Midori, and Gokou are tea cultivars which are developed from tea plants native to the region.

2.2 Terroir Concept

Understanding the concept of terroir elements utilized in this research would be crucial in developing bio-climatic indicators for the Uji area which are important for looking at the phenological impact of terroir conditions. Derived from viticulture, the terroir has been regarded as one of the most important factors in grape growing and wine making. Van Leeuwen and Seguin (2006) explained that terroir concept describes the relationship between the characteristics of an agricultural product and its geographical origin. The latter which includes traditional agricultural practices, influence the characteristics of the former.

Through the notion of terroir it can be argued that the special quality of an agricultural product is determined by the character of the place where the product comes from (Gade, 2004). In growing grapes for wine, human factors such as history, socio-economic conditions, as well as viticultural and oenological techniques, are also part of terroir (Seguin, 1986). In regards to the original concept and the scope of this research, the terroir concept is also linked to the unique bio-physical properties of a particular area (Bernard and Marchenay, 2006) which affects the quality of the resulting agricultural products.

Based on these definitions the terroir concept in this inquiry is defined as a relationship between natural environment elements and agriculture practices elements where these elements directly influence the characteristic of an agricultural product. In this definition terroir concept consist of two elements which are: 1. Natural Environmental Elements and; 2. Agriculture Practices Elements. The two elements represent the natural and human geographical characteristic of Uji Area and the accumulation of cultivation knowledge inherited down through generations of tea growers in the area.

Natural environmental elements consist of: climate, soil, topography and cultivars. Among these four environmental factors, this research especially emphasizes the climatic factors as changing climatic conditions will have a direct and indirect effect towards the tea cultivation process and its final products. The other important element in the terroir concept is the agriculture practice elements which are the basis of tea cultivation knowledge in Uji Area, where this knowledge is largely family inherited knowledge, passed down through successive generations of the tea grower's family.

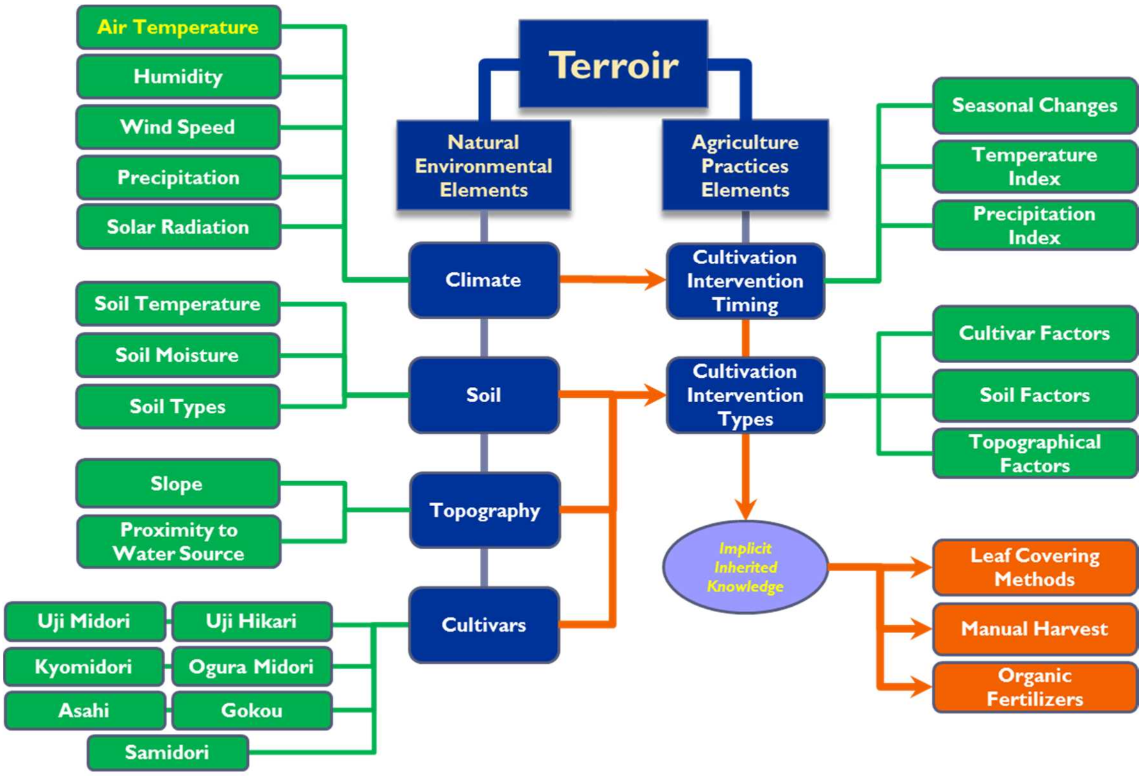


Figure 2.2 Terroir Concept of Tea Cultivation in Uji Area

2.3 Natural Environmental Elements

As one of the important elements in the terroir concept, natural environment elements are the factors which represent the unique characteristics of the environmental condition in a certain cultivation area. The important factors in this elements are climate, soil, topography and cultivar factors. Combination of these four main factors have shaped and created the natural condition which is unique for that area. Thus agriculture plants, such as tea which are grown under those specific conditions would produce products which have certain characteristic derived from the unique natural condition. In order to fully understand these factors measurements and analyses are required to clearly identify the interacting factors.

2.3.1 Climate

Climatic factors consist of indicators which are directly related to the micro-climate[3] and meso-climate[4] of the agriculture area, whereas some of other environmental factors characteristic are directly influenced by changes in the climatic conditions. There are indications of a rapid transformation in the climatic condition, therefore these will undoubtedly change the characteristic in different environmental factors. The five indicators listed below are considered the most important factors in the tea cultivation (Tea Research Institute of Sri Lanka, 2008; Kyoto Prefecture Tea Industry Research, 2014):

- Air Temperature (ºC)
- Humidity (%)
- Wind Speed (m/S)
- Precipitation (mm)
- Solar Radiation (W/m^2)

Other advance indicators which are a combination of several indicators, are also important to understand the impact of changing climatic conditions, especially during important periods in the cultivation process. Air temperature is one of the most important factor in the climate elements. It can be further broken down into several indicators such as average temperature, minimum temperature and maximum temperature.

[3] Micro-climate is defined as the climatic condition in a specific location such as the area of a tea plantation.
[4] Meso-climate is defined as the climate in a particular area inside a tea growing region.

In this research although observations of temperature are aggregated at hourly intervals the observations can go down to as short as minute-based intervals where required. The obtained data is converted in this study to the time dimension of a daily average, daily minimum and daily maximum temperature. Tea plants in general are active in conditions where air temperature is above 10^{o}C and would enter dormant state when it's below 10^{o}C. It is clear that these internal mechanism of the plants which are crucial in the cultivation process are largely dependent on the air temperature condition.

Humidity factor is largely affected by air temperature and precipitation level, thus occurrences of evapo-transpiration from the soil and plant leaves would directly influence the humidity level. Wind speed factor also indirectly affects not only humidity factor but also air temperature. Absence of wind can increase humidity level, whereas strong wind can lead to a sudden gust, heavy downpour and also further dropping the air temperature, thereby causing frost events. The quantity of solar radiation received by the plants would then signal the plant's metabolism to continue its phenological processes. Excess quantity of solar radiation would also lead to the increase of maximum day time air temperature. In extreme instances, this will lead to serious issues such as drought in complement with the absence of precipitation.

In this research changes in the average mean temperature, average minimum temperature and average maximum temperature and how it affects tea cultivation are observed. Through observation of the climatic data, fluctuations of the values could be identified and analyzed in order to understand how these changes have been affecting the tea cultivation process. The data thus analyzed is correlated with the results of the social survey conducted and observation which conducted with Uji Area tea growers. The research methodology of the study is elaborated in section 2.6 while the analysis of changes in the climatic values and the correlation between climatic data and social observation are further discussed in chapter 3.

Based on the correlation analysis conducted between measured climatic values with tea cultivation interventions which are conducted by the tea growers, important bio-climatic indicators could be developed. How these bio-climatic indicators could be utilized in assisting the tea cultivation process to cope with the rapid environmental change is be discussed in chapters 4 and 5.

2.3.2 Soil

Indicators of soil factors mainly refers to the physical properties and conditions of the soil. They include:

- Soil Temperature (^{o}C)
- Soil Moisture (cb)
- Soil Types

These conditions are largely influenced by changes in the air temperature and quantity of precipitation. Thus, the areas covered by plant also influences these changes acting as a buffer zone limiting penetration of sunlight and thereby minimizing the temperature changes on the surface of the soil. Generally in Uji Area there are two types of soil, namely those where clay or sand predominate. In several tea plantations, tea growers are mixing the two soil types to obtain certain results. Based on anecdotal information obtained from tea growers it was mentioned that tea plants which are grown on sand type soils would produce teas with better tea aroma and deeper green color, whereas those which are grown on clay type of soil would produce teas which have strong flavor.

Among different soil types, sandy soil has large particles therefore because there are spaces among the particles in general it has a low water retention and nutrients runoff is more frequent. Clay soil on the opposite it has small particles with smaller space in between, which made clay soil have a good water retention properties. Soil properties on the tea plantations in Uji Area are generally heavily maintained as discussed in sub chapter 2.5 whereas it was found in the social surveys and observations data, the tea growers applied different types of organic fertilizers in a different timing, and also conducted deep soil maintenance periodically.

These activities would ensure the soil health of their tea plantation as well as ensuring that enough nutrients are available for the tea plant growth. How changes in the climatic conditions affect the soil properties is relevant to the soil maintenance activities conducted by the tea growers, this is discuss further in chapter 3.

2.3.3 Topography

In Uji Area topographical factors are closely related with soil factors. Clay soil type is found on the hill side while sand soil type is mostly found near the river bed and flatlands. In general the topographical factors in Uji Area consist of:

- Slope
- Proximity to water reservoir (m)

These factors directly influence the tea cultivation practices. Tea plantations which are located in the hill side are subject to a lower winter temperature and fewer frost incidents, with a lower probability of experiencing drought. Also because clay soil have a better moisture retention and the surrounding areas are mostly forest with high canopy they shade the tea growing area and minimize water loss. Because of its location on slopes cultivation practices are slightly more complex, since the topographical gradient of the plot has to be such that it achieves optimal water flow.

Tea plantations which are located around the river bed and flatlands are mostly around residential areas with easy access. Because of its location these plantations are more vulnerable to extreme weather events such as high temperature, drought and face the risk of flooding during heavy downpour. In parallel with its vulnerabilities easy access to water reservoir and direct proximity to the city drainage system would allow tea growers to effectively manage the water flow in their tea plantation.

Impacts of the changing climatic conditions are different based on the topographical factors of the tea plants. Thus for the tea growers, it also affects their decision making with respect to conducting cultivation interventions on their tea plants. This is explained further in chapter 3.

2.3.4 Cultivars

Cultivars are defined as cultivated varieties which are native to the area or specially created through selective plant breeding in order to further utilize the characteristic of the natural environment elements. Tea seeds first came to Uji Area from China around 1191 AD and soon after that tea cultivation began in Uji Area. For more than 500 years of tea cultivation, the natural adaptation capabilities of the tea plant have made the plant to be able to grow optimally with the climate in Uji Area. With these qualities the tea plants have developed characteristics which are only attributable to those which are native plant. Apart from this, varieties of tea plants in Uji Area have also grown from selective plant breeding which is conducted by tea growers.

In order to achieve certain desired traits of the tea plant, especially to further optimize them to the micro-climate condition, tea growers have to carefully select and breed tea plants based on each characteristic. As mentioned previously there are eight varieties of tea plants which are developed inside Uji Area: Uji Midori, Kyomidori, Samidori, Asahi, Uji Hikari, Ogura Midori, and Gokou. Although currently there are only seven varieties of tea plants which have originated and are registered from Uji Area currently being cultivated, there are many undocumented varieties of tea plants which are exclusively bred and cultivated by many tea growing families in Uji Area.

Currently samidori cultivar is the most widely cultivated variety by tea growers in Uji Area, with the composition of samidori cultivar in most of the tea plantations are around 70 percent to 80 percent while other tea cultivars make up the rest. Although samidori cultivar does not produce high quality tea leaves, because of its long window of harvest period and the resistance to the cold, it is selected to mitigate risk factors due to climatic and environmental conditions. This thesis suggests that with precise climatic information and the derived from bio-climatic indicators, tea growers would be able to increase the composition tea cultivars which are more sensitive towards climatic conditions but producing high quality tea leaves.

2.4 Agriculture Practices Elements

These elements describe the influence and the importance of human factors in an agriculture process, especially in this inquiry on Uji Tea cultivation. As part of the important elements in the terroir concept, tea cultivation practices which are being used by the tea growers in Uji Area are distinct and irreplaceable in order to produce Uji Tea. These practices utilize cultivation knowledge, which is an accumulation of experiences obtained by previous generations of tea growers, continuously passed down in their family until the present day. This tea cultivation knowledge is unique and native to Uji Area, as it has been developed based on the natural characteristic of Uji Area's environmental factors. Cultivation interventions and special cultivation methods which are invented and used for tea cultivation are designed to fully utilize the unique characteristics of the environment.

These interventions and special methods are utilized mainly based on two deciding factors which are: timing of cultivation intervention and types of intervention applied during the cultivation process. Both these deciding factors are influenced by the four environmental factors in order to obtain the desired products. These types of interactions between the environmental elements in Uji Area and the tea grower's interventions are unique and only exist in Uji Tea cultivation, therefore the interactions between terroir elements in Uji Tea cultivation have to be fully comprehended in order to identify important bio-climatic indicators.

2.4.1 Cultivation Intervention Timing

Through years of experiences and observations, the tea growers in Uji Area have been able to understand how the micro-climate condition changes in their own tea plantation down to the smallest plot. By understanding these conditions tea growers were able identify the correlation between micro-climatic conditions with phenological process of the tea plants. Based on this knowledge the tea growers in Uji Area were able to conduct cultivation interventions which are best suited to those conditions, especially to bring out the unique characteristic of tea products cultivated in Uji Area. Based on preliminary observation on tea cultivation process, timing of the cultivation intervention conducted by the tea growers are mainly based on:

- Seasonal Changes
- Temperature Index
- Precipitation Index

Some of the original cultivation methods which are conducted by Uji Tea growers such as leaf covering, organic fertilizer and soil maintenance are conducted depending on the season and changes in the climatic factors. Tea growers would start covering the tea leaves around mid-spring when the temperature is warm. Application of fertilizer and soil maintenance are also conducted depending on the season and precipitation in the tea plantation. From this information it can be correlated how changing climatic conditions will affect the decision to time cultivation interventions. In this thesis the argument for the development of the bio-climatic indicators is presented so that it would help tea growers and is discussed in chapters 4 and 5.

2.4.2 Cultivation Intervention Types

The second factor in the agriculture practices describes the types and kinds of cultivation intervention which are utilized in Uji Area. The types of cultivation interventions selected by the tea growers are mostly motivated by the desired final products. Each tea grower will utilize cultivation interventions which are most suited to the natural environmental condition of their tea plantation. Based on preliminary observation in the tea cultivation process most of the decision factors are based on:

- Cultivar Factors
- Soil Factors
- Topographical Factors

Based on the combination of soil conditions, slope of the tea plantation and types of varieties planted, tea growers can select the most suitable cultivation methods in order to achieve desirable harvest quality and quantity. As mentioned previously, selecting the exact timing for conducting original cultivation methods such as leaf covering, composition of organic fertilizer and soil maintenance depend on the seasonal and climatic changes. Based on the cultivars, soil and topographical factor, the degree to which any of these three methods are conducted will be varied, while sometimes farmers would even conduct different methods, such as the introduction of a watering system, frost fans and other methods. Similarly with the cultivation intervention timing, the impact of the climatic changes as well as the values of bio-climatic indicators are important and it is discussed further in chapters 4 and 5.

2.5 Tea Cultivation Practices in Uji Area

For generations tea growers in Uji Area retain traditional cultivation methods which rely heavily on manual labor for the cultivation processes, as well as manual leaf plucking during tea harvest. One of the unique cultivation methods utilized by the tea growers in Uji Area is the use of traditional covering methods during the tea cultivation period and knowledge of this practice is passed down through generations of tea farmers. This method is especially essential to produce high quality *matcha* and *gyokuro*.

2.5.1 Leaf Covering Method

This unique method was invented by Uji tea masters around 400 years ago, where tea bushes are covered with sunlight blocking materials at the moment of first bud break for approximately three to four weeks. In the first two to three weeks the light intensity is reduced by 95 percent and in the last week prior to harvest, the light intensity is further reduced to 98 percent. Based on findings by Kimura and Kanda (2013) it was found that cultivated leaves under reduced sunlight condition using the leaf covering greatly reduce the penetrating ultra-violet rays to the tea plants which caused the tea leaves to be thinner. It was also identified that the leaves which are cultivated under leaf covering showed increase chemical contents of free amino acid and caffeine (a purine compound of the methylxantine class, which is a central nervous system stimulant). Anecdotal information Under reduced sunlight condition the tea leaves are forced to produce more chlorophyll thus this will reduce the level of *catechin* (a phenol belonging to the flavonoid family, which is an anti-oxidant) and is believed to give more taste and sweetness to the tea produced (Ujicha Cooperative, 2013).

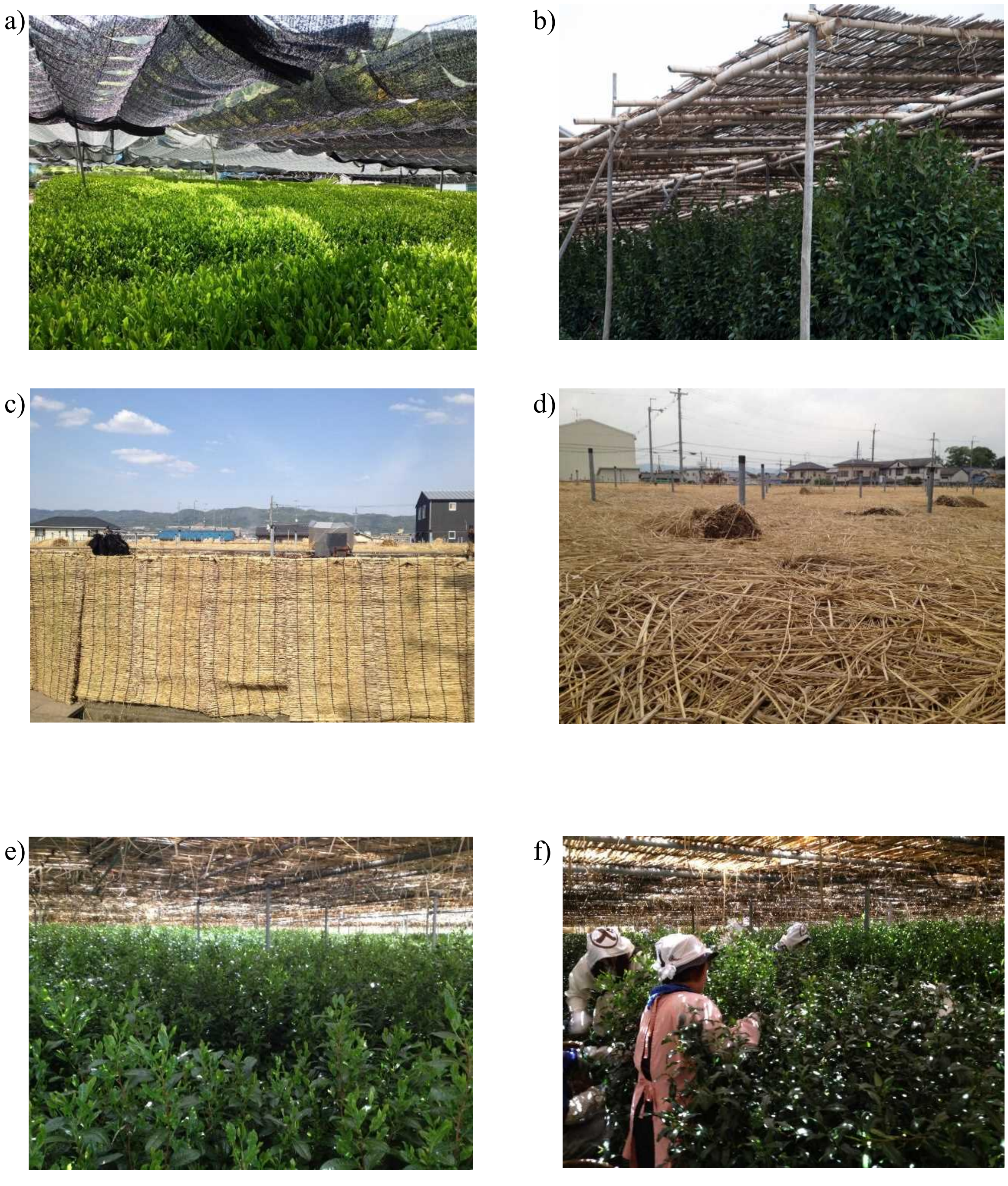
Based on preliminary surveys and observations conducted (Ashardiono & Cassim, 2014), it is revealed that tea farmers have their own methods and system to achieve reductions in light intensity. The observed variation includes: 1) selection of covering material; 2) layering methods and installation height; 3) duration of covering period. Covering materials used in this method traditionally use two layers. The first layer is *yoshizu*（葦簀）which is a mat made from reeds and split bamboo tied together, while the second layer is straw which is evenly distributed on top of the mat.

Because the traditional methods require reeds mat and straws, which have increasingly become expensive, currently many tea growers are also using other artificial covering materials such as two layers of black vinyl sheet. This covering method contributes directly to the flavor and taste characteristic of Uji Tea. Because of this complex and resource consuming cultivation method, tea harvest in Uji Area can only be conducted once a year.

Although currently most tea farmers in Uji Area use the black vinyl sheet for covering, interestingly they always have several small patches of tea plants which are covered using the traditional style using reed mats and straws in their tea plantation. This could be explained through the recent findings that ultraviolet radiation does penetrate the black vinyl covering whereas ultraviolet rays hardly penetrated the covering made from reed mats and straws (Kimura and Kanda, 2013).

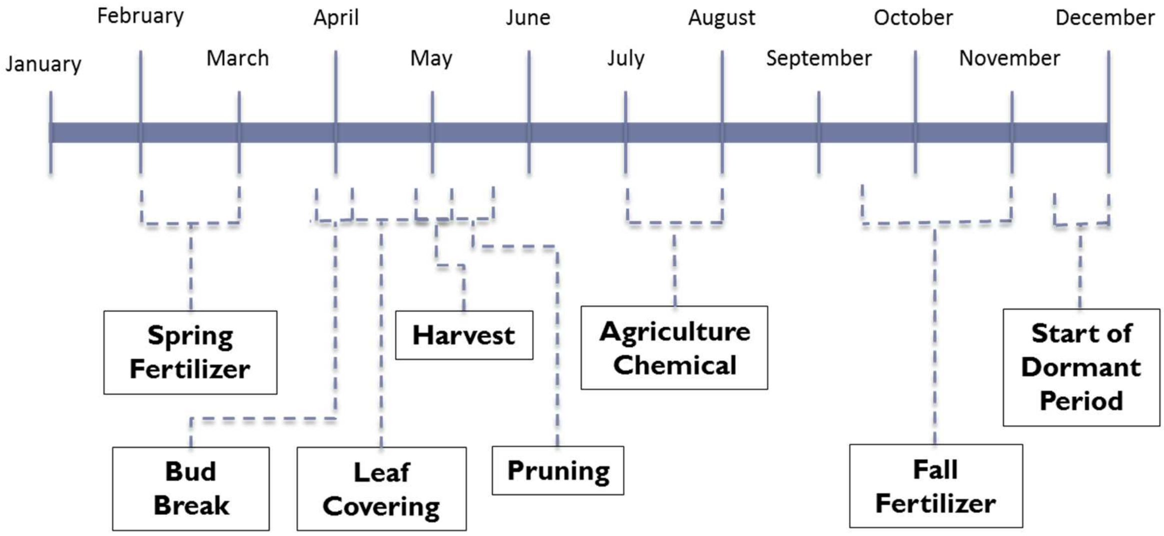
Although in other parts of Japan for Japanese green tea cultivation covering method is also used, other growing regions used the coverings directly on top of the tea plants, whereas in Uji Area the plantation itself is completely covered with the covering materials, effectively reducing the sunlight up to 98 percent. The covering methods which are used in other tea growing regions in Japan apparently originated from the covering method used in Uji Area.

In general covering is done in two stages for a period of approximately 21 days. In the first two weeks of the period, only one layer of covering is used to block the sunlight up to 90-92 percent. Upon entering the third week of the period until harvest, the second layer of covering is used to block the sunlight up to 98 percent, and the plantation will continue to be shrouded with the covering until the whole plantation has been harvested.



(Source: Author, 2014)

Figure 2.3 (a) Covering method using black vinyl sheet; (b) (c) (d) Traditional covering method using woven reeds and straws; (e) Tea bushes under covering method; (f) Manual leaf harvesting under traditional shades



(Source: Author, 2014)

Figure 2.4 Typical Tea Cultivation Period in Uji Area: Major Phenological Landmarks and Cultivation Interventions

2.5.2 Manual Harvest

As mentioned previously, tea cultivation in Uji Area is mostly conducted using traditional methods, which include leaf harvesting. Although in other tea growing regions in Japan, tea growers are utilizing mechanical equipment for leaf harvesting, the tea growers in Uji Area are still using manual methods by employing leaf pluckers during the harvesting period. Manual tea leaf plucking ensures the quality of the harvest because the pluckers will only pluck young leaves, leaving out the thick and old tea leaves. Manual harvest also ensures the leaf is undamaged, which is crucial to maintain the freshness of the leaf as damaged leaf will change the tea flavor because the onset of oxidation.

Manual harvesting on the other hand could only produce a limited yield per day because it is fully depends on how many tea pluckers are working on the tea plantation.

On average one tea plucker would be able to harvest 1 kg of fresh tea leaves for an hour. It would take approximately 5-6 days to manually harvest an area of 200 m^2 of tea plantation employing 4-5 tea pluckers, while it would only take one day using a mechanical leaf harvester.

Despite how this harvesting method is conducted, it consumes a large amount of labor resources, leading to low land and labor productivity levels, the quality of tea leaves harvested in Uji Area would have to be incomparably high relative to other tea growing regions in Japan. By ensuring that only high quality tea leaves are plucked, tea growers could minimize the changes in the quality of their tea harvest each year while being mindful of changes in the climatic conditions during each season.

a)

b)

c)

(Source: Author, 2014; Kyoto Prefecture Tea Industry Research, 2014)

Figure 2.5 (a) Manual leaf harvesting under shading net; (b) Manually harvested tea leaves; (c) Mechanical leaf harvesting

2.5.3 Organic Fertilizers

Apart from unique covering methods and manual harvesting, other traditional tea cultivation methods which are still being used by the tea growers related to the use of organic fertilizers. Tea growers in Uji Area applied a complex and dedicated regime of fertilizers to the tea plants of which nearly all are organic fertilizers. As seen in figure 2.4 in general fertilizers are applied in two periods on each planting season. In the spring period prior to leaf bud break, as early as late January, Uji tea growers start applying fertilizers to the tea plant where the purpose is to ensure that the tea plants obtained enough nutrition to grow high quality leaves. The second fertilizer application period is conducted somewhere between September and October as soon as the dry season has passed. In this period, application of fertilizer will provide the essential nutrition for the plants to save and build up prior entering the winter season. Each tea grower has his/her own methods in applying the fertilizer, with variation in the types of fertilizer, quantity applied as well as timing of the application. Based on preliminary observation, there are several types of organic fertilizer which the farmers commonly use, which are: 1) Aburakasu (vegetable oil dregs); 2) Konakasu (Dregs in powder form such as coffee dregs, etc); 3) Gyohi (fish remains and fish oil); 4) Calcium derivatives (oyster shell, crab shell, cow bones, etc).

Tea growers in Uji Area use types of organic inputs describes above into their fertilizer, and the knowledge on how to properly create and apply such fertilizer mixes are obtained from their families. Bio-chemical properties of these products indicated that fish remains provide the much needed amount of nitrogenous compounds as well as increased amino acids input which gives the flavor characteristic of Uji tea. Although originally these products were waste from other production processes, currently tea growers have to specially order these products. Uji tea growers believe that application of these organic products are one of the important factors which give Uji tea its distinct characteristics.

a)

b)

c)  d) 

(Source: Author, 2014))

Figure 2.6 (a) Ground crab shell; (b) Fish remains and fish oil;
(c) Aburakasu (vegetable dregs and oil); (d) Cow bones

2.6 Research Methodology

In order to answer the research questions stated in the previous sub chapter 1.4 the research is conducted using mixed methods, utilizing both quantitative and qualitative analyses.

2.6.1 Quantitative Analysis

Quantitative analysis is utilized to analyze numerical data sets which are generated from direct climatic measurement and recording as well as secondary source of climatic data sets which are obtained from the weather station operated by Kyoto Prefecture Tea Industry Research. The primary climatic data sets are acquired from two weather stations which are installed in two locations in Uji Area, in the vicinity of tea plantation which the owner is a research collaborator. Locations of these weather stations could be seen at figure 3.8.

Direct climatic data monitoring and measurement were conducted according to the climatic factors which were listed is sub chapter 2.3.1 whereas approximately there are 10 data sets which were recorded from each station. From the two weather stations, climatic data monitoring and recording are conducted within 5 minutes interval for one year period, thereby made the total number of recorded data as many as 2 million data sets. These data sets then are organized in chapter 3 and analyzed in chapter 4, following the methods which utilized by the Kyoto Prefecture Tea Industry Research.

The data acquired from Kyoto Prefecture Tea Industry Research Institute consist of 5 data sets for 12 years period which were recorded in one hour interval. These data were averaged into three parts for each month. Each part consists of values which are averaged for 10 days, which represents the first 10 days of the month (early), the second 10 days of the month (middle) and the last 10 days of the month (late). Quantitative analyses methods such as variance analysis and regression analysis then were conducted to these data sets, along with the tea production data and statistics which are obtained from Kyoto Prefecture.

2.6.2 Qualitative Analysis

Qualitative research approach is utilized in conducting social surveys and observations in this research. In order to obtain detailed information on the agriculture practices elements, as this knowledge is implicit and inherited by the tea growers, conducting direct interviews and observation on the tea cultivation are definitely required. The interviews are conducted using a semi-structured style approach, following Mason (2002) who describes the core features of a qualitative semi structure interview as follows:

1. The interactional exchange of dialogue, as interviews may involve one-to-one interactions, larger group interviews or focus groups, and may take place face to face or over the telephone.
2. A relatively informal style, for example, with the appearance in face-to-face interviewing of a conversation or discussion rather than a formal question and answer format.
3. A thematic, topic centered, biographical or narrative approach, for example, where the researcher has a number of topics, theme or issues which they wish to cover, or a set of starting points for discussion, or specific 'stories' which they wish the interviewee to tell. The researcher is unlikely to have a complete and sequenced script of questions, and most qualitative interviews are designed to have a fluid and flexible structures, and to allow researcher and interviewees to develop unexpected themes.
4. Most qualitative research operates from the perspective that knowledge is situated and contextual, and therefore the job of the interview is to ensure that the relevant contexts are brought into focus so that situated knowledge can be produced. For some this extends into the assumption that data and knowledge are constructed through dialogic (and other) interaction during the interview. Most would agree that knowledge is at the very last reconstructed, rather than facts simply being reported, in interview setting. According to this perspective, meanings and understanding are created in an interaction, which is effectively a co-production, involving researcher and interviewees.

From the interview results, Mason (2002) discusses on the possibility of ethical challenges arising. There are two ways in which such ethical issues could appear:

1. The rich and detailed character of much qualitative research can mean intimate engagement with the public and private lives of individuals.
2. The changing directions of interest and access during a qualitative study mean that new and unexpected dilemmas are likely to arise during the course of the research.

During the interview survey conducted in this research, the questions were structured following Mason's guidelines and organized as follows: 1) Demographic Information; 2) Agriculture Knowledge; 3) Terroir Comprehension; 4) Opinion on Climate Change; 5) Seasonal Cultivation Process; 6) Utilization of Precision Agriculture; and 7) Socio-Economic and Environmental Issues. The complete script of this semi-structure questionnaire is attached in the appendix section of this thesis.

During interviews, the author carefully placed attention to questions which might be related to the inherited tea cultivation knowledge by observing how the respondent reacted with the questions. Based from the reactions, the author would then decide to probe deeper or not on the issues depending on whether the respondent reaction seems to be comfortable with the questions asked or not. If the latter, the author would divert the questions to the main guideline with less sensitive questions which brings back a conducive environment during the interviews. The author has always tried to make the respondents comfortable with the questions given, creating conducive environment which makes the interviewing process enjoyable for both parties, like a conversation between friends.

As previously mentioned, in this research observation of tea cultivation practices are also conducted to further understand the types and timing of the cultivation intervention which were used by the tea growers, especially to understand the correlation between the selected interventions with the conditions of the environmental elements.

2.6.3 Research Stages

As shown below in figure 2.7 this research is divided into three stages, where each stage represents analysis and discussion on the stated three main research questions.

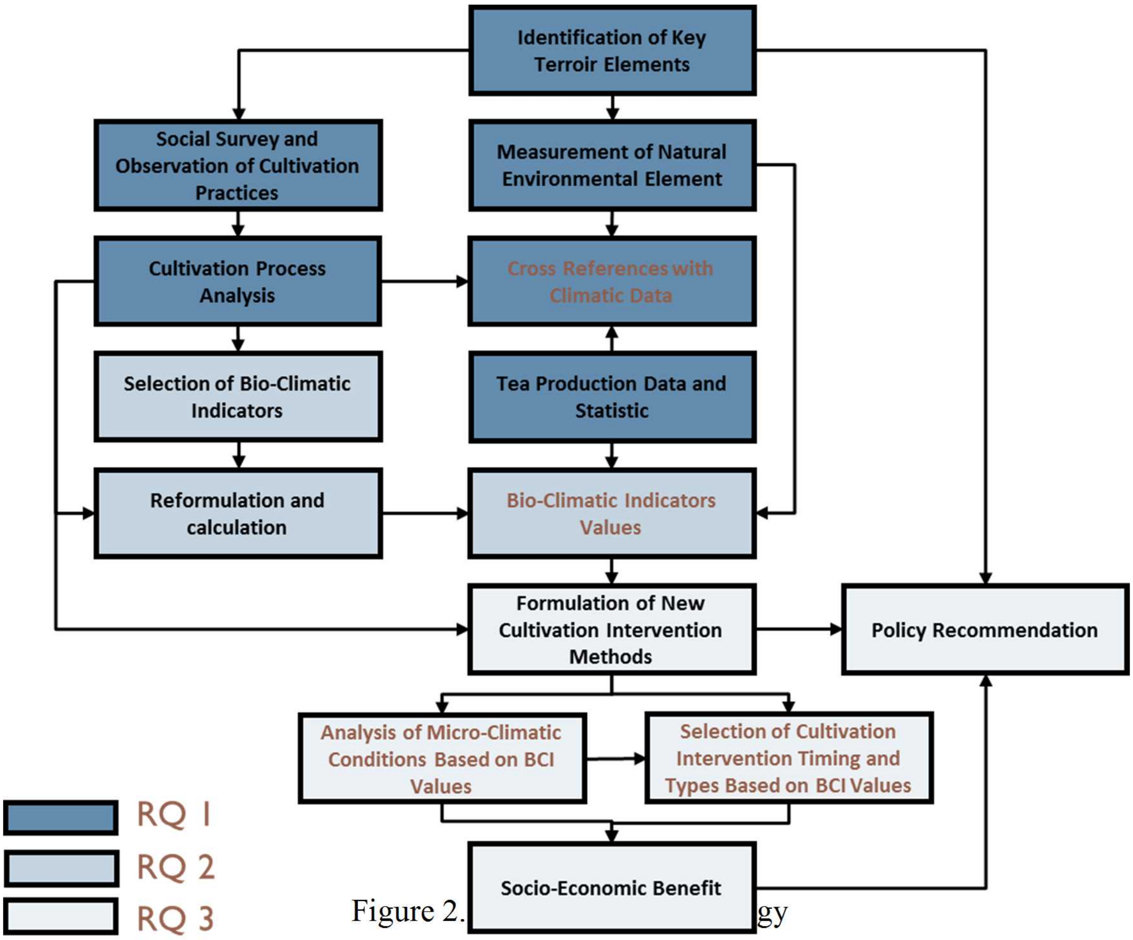


Figure 2. gy

The first stage of this research (highlighted in blue color) is focused on the inquiry of RQ 1, thus it is focused to understand how the changes in the climatic factors have affected the other terroir elements which are identified through this research. The inquiry begins with identification of key terroir elements based on preliminary researches, and from the identified terroir elements, goes on to direct measurement of natural environmental elements as well as obtaining secondary data, especially on climatic factors are conducted.

These data measurements and gathering were conducted in parallel with the social survey and observation of tea cultivation practices to understand the agricultural practices elements in Uji Area. From the results of the survey and observations a complete cultivation process analysis of Uji tea cultivation could be constructed. Thus through cross referencing between natural environmental elements data with cultivation process analysis and tea production data as the base for interpretation, how significantly does the climatic factor impact the other terroir elements in tea cultivation could be further understood through the analysis.

In the second stage which is focused on RQ 2 (highlighted in light blue color), the previously constructed cultivation process analysis is further developed by introduction of bio-climatic indicators derived from winegrape cultivation. Through selection and modification, bio-climatic indicators which are especially adjusted for tea cultivation could be developed and correlated with the tea production data, thereby showing that the values indicated by these bio-climatic indicators could be utilized in the tea cultivation process.

In the third stage focused on RQ 3 (highlighted in light gray), application of these bio-climatic indicators for developing new tea cultivation intervention methods is explored, and through the utilization of these indicators the tea growers would be able to obtained precision information about the natural environment conditions, thereby allowing them to analyze and further understand the micro-climatic condition affecting the phenology of the tea plants in their tea plantation. From this analysis they would be able to select effective cultivation intervention types and decide effective timing in conducting cultivation interventions, whereas from these new cultivation intervention methods the tea growers would be able to swiftly adapt with the on-going changes in the climatic condition, as well as maintain and enhance their tea products.

In the broader correlation, this condition would bring in and increase the socio-economic benefit for Uji tea growers' community by preservation of traditional tea cultivation methods as well as by enhancing the product values. These findings then would be further discussed to construct a policy recommendation for application of the terroir elements in order to develop bio-climatic indicators for Uji Area tea cultivation.

CHAPTER 3

OBSERVATION OF CHANGES IN THE TERROIR ELEMENTS OF UJI AREA

3.1 Natural Environmental Elements

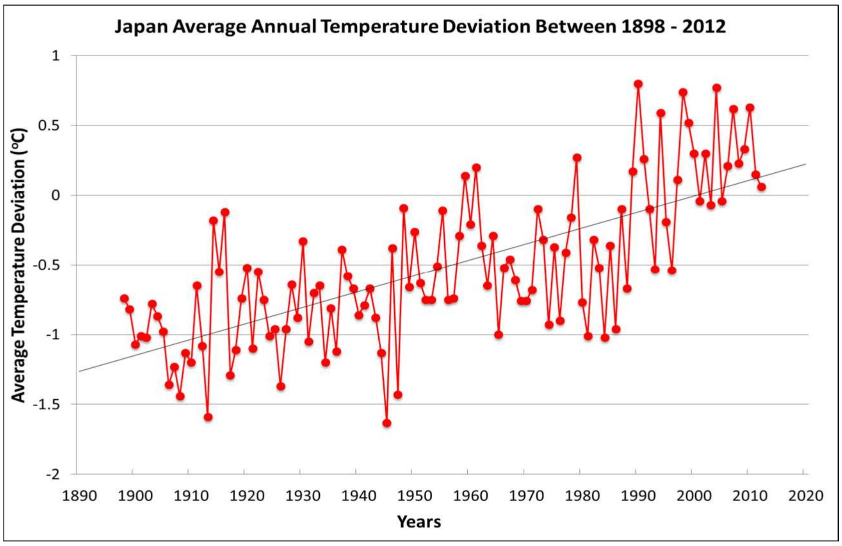
Recorded climatic data from a long term observations indicate that in general the average temperature is increasing in many parts of the world. Increase of the average temperature might be beneficial for agricultural production as colder climate region become warmer; cultivation of crops which before was impossible becomes feasible. But on the contrary currently well-known cultivation regions might become unsuitable for certain crop cultivation in the future as the temperature gradually becomes too warm. In winegrape cultivation it was predicted changing cultivation condition might trigger a shift in suitable location for some varieties of cultivation in order to obtain high quality harvest (Jones, 2007). These changes would lead to the loss of knowledge for adaptation in the older cultivation regions.

The influence of higher temperature on tea cultivation would reduce tea yield as stated by Wijeratne, 1996. Based on climatic data obtained from Japan Meteorogical Agency (2011) for 120 years period from 1891 to 2011 showed in figure 3.1 clearly showed that the average temperature trend is increasing by 1.15^{o}C over a 100 Year period.

Japan Meteorogical Agency (2005) has also released its projection of possible changes in Japanese climate by the end of the twenty first century.

1. Average temperature will increase from 2.0 to 3.2^{o}C, with a 1^{o}C increase by 2030. Increase will be significantly greater at higher latitudes.

2. Increased frequency of abnormal higher temperatures. Hot days, air temperature is higher than 30ºC, may extend over almost 4 months in summer
3. Annual precipitation will increase, except for the southern Kyushu Area, while seasonal winter and spring precipitation will decrease in most regions. The number of no-rain days will increase across most of Japan,
4. Snowfall will decrease across the whole of Japan, except for the coast of the Sea of Okhost.
5. The magnitude of Typhoons will increase.



Source: Japan Meteorogical Agency, 2012

Figure 3.1 Japan Average Annual Temperature Deviation (1898-2012)

3.1.1 *Average Mean Air Temperature*

As previously explained, the climatic data which are obtained from Kyoto Prefecture Tea Industry Research (2015) consist of hourly data in the first flush cultivation tea cultivation period from early January to early May (1:January; 2:February;

3:March; 4:April; 5:May) which are averaged into beginning (a), middle (b) and late (c). Based from observation on this data (table 3.1), there are indications that the fluctuations in the average mean air temperature on each period have become more apparent in the past years, especially it is clearly identifiable from how the values on the same period have varied over the years.

	1a	1b	1c	2a	2b	2c	3a	3b	3c	4a	4b	4c	5a	Mean	Median	Std Dev
2002	3.9	1.3	3.7	4	3.6	5.6	5.1	6.8	10.3	12.4	14.7	13.1	17.8	7.869	5.6	5.184
2003	3.5	7.1	4.3	5	3.6	8.3	6.7	10.7	10	14.2	14.6	17	18.8	9.523	8.3	5.209
2004	5.1	4	2.7	3.8	5.6	8.1	5.3	9.4	10.3	11.9	17.5	15.2	18.7	9.046	8.1	5.385
2005	3.7	4.1	4.2	4.3	5.4	3.5	6.2	6.7	8.7	13	14.1	17.3	18.1	8.408	6.2	5.345
2006	2.5	4.9	3.2	3.2	5.6	6.9	6.7	6.2	7.5	10.6	13	13.2	18.8	7.869	6.7	4.772
2007	4.9	4.6	4.9	6	6.2	7.4	8	4.6	10.3	10.4	13.1	16	18.5	8.838	7.4	4.584
2008	5.3	4	3.8	2.9	3.4	4.1	5.9	11.5	10.7	12	14.5	16.4	19.1	8.738	5.9	5.569
2009	5	3.6	5.9	5.1	7.1	7.5	7.9	9.7	8.3	11	17.5	14.1	18.1	9.292	7.9	4.673
2010	4.4	3.7	4.9	5	4.6	11.4	8.8	9.9	7.4	12.6	13	13.1	18.8	9.046	8.8	4.586
Mean	4.256	4.144	4.178	4.367	5.011	6.978	6.733	8.389	9.278	12.011	14.667	15.044	18.522			
Std Err	0.309	0.502	0.324	0.333	0.431	0.793	0.424	0.787	0.436	0.406	0.582	0.572	0.143			
Median	4.4	4	4.2	4.3	5.4	7.4	6.7	9.4	10	12	14.5	15.2	18.7			
Mode	#N/A	4	4.9	5	3.6	#N/A	6.7	#N/A	10.3	#N/A	17.5	13.1	18.8			
Std Dev	0.928	1.506	0.971	0.999	1.293	2.379	1.272	2.360	1.307	1.219	1.747	1.715	0.429			
Smpl Var	0.860	2.268	0.942	0.997	1.671	5.662	1.618	5.571	1.707	1.486	3.052	2.943	0.184			
Kurtosis	-0.187	2.838	-0.014	-0.714	-1.119	0.489	-1.032	-1.335	-1.714	-0.229	-0.246	-1.921	-0.903			
Skewness	-0.732	0.145	0.270	0.046	0.104	0.261	0.345	-0.300	-0.498	0.327	0.970	0.016	-0.537			
Range	2.8	5.8	3.2	3.1	3.7	7.9	3.7	6.9	3.3	3.8	4.5	4.2	1.3			
Min	2.5	1.3	2.7	2.9	3.4	3.5	5.1	4.6	7.4	10.4	13	13.1	17.8			
Max	5.3	7.1	5.9	6	7.1	11.4	8.8	11.5	10.7	14.2	17.5	17.3	19.1			
Sum	38.3	37.3	37.6	39.3	45.1	62.8	60.6	75.5	83.5	108.1	132	135.4	166.7			
Count	9	9	9	9	9	9	9	9	9	9	9	9	9			

Source: Kyoto Prefecture Tea Industry Research, 2015

Table 3.1 Average Mean Air Temperature (^{o}C) Between Early January to Early May (2002-2010)

Further statistical analysis illustrated in figure 3.2 have showed, based on the seasonal average mean air temperature values there are tendencies for the value to increase, whereas statistical analysis on each period have found an identifiable temperature fluctuations in the mean average temperature for the values on late February (2c) and mid March (3b). From this result it could be interpreted that there is an indication of temperature fluctuation towards higher temperature especially in late February (2c), there are also tendencies for the average mean air temperature to fluctuate more towards higher temperature on the first flush tea cultivation period.

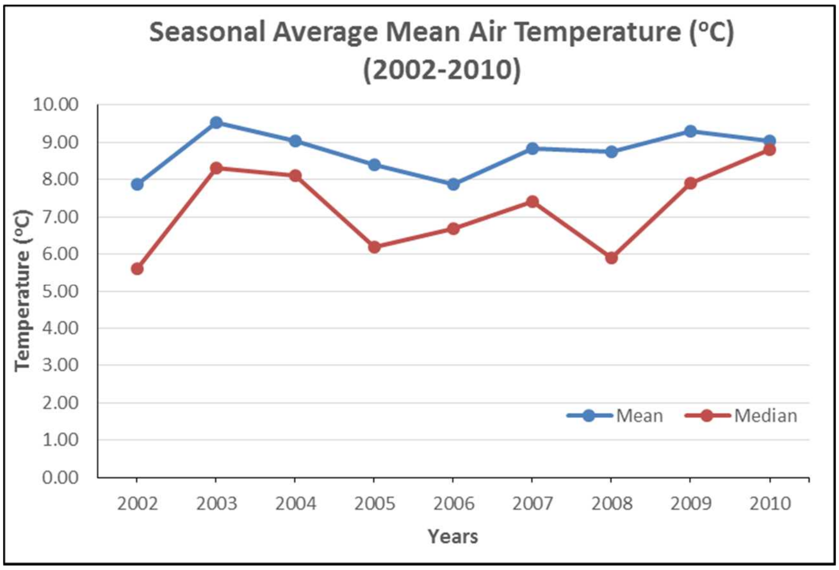
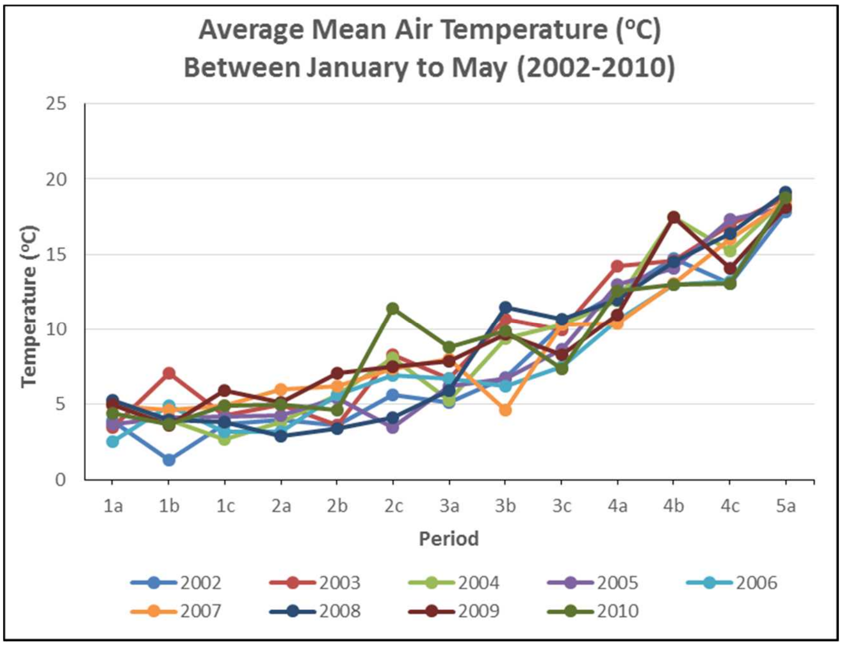


Figure 3.2 Seasonal Average Mean Air Temperature (°C) Between Early January to Early May (2002-2010)



Source: Kyoto Prefecture Tea Industry Research, 2015

Figure 3.3 Average Mean Air Temperature (°C) Between Early January to Early May (2002-2010)

Tea plants in general are in dormant state at temperatures below 10^{o}C especially during the winter period of December to February, whereas any occurring temperature fluctuations especially sudden temperature increase, will directly affect the tea plant metabolism and consequently the plant phenology in this period. Tea plants do not actually go into complete dormancy as because they still retain their leaves throughout the winter indicating that its metabolism became very slow. Occurring temperature fluctuations which temporarily increase the average mean air temperature in this period (as seen in late February (2c)) would signal the tea plants to end its dormant state and increase its metabolism rate above ground.

This early growth will be abruptly stopped if the average mean air temperature suddenly decreased, damaging the tea plants especially the growth of the new leaf buds. Regarding whether it has affected the harvest quantity, based on anecdotal information the fluctuations are also reported to affect the plant phenology, especially the growth of tea leaves, leading to a declining harvest quality. These changes would be detrimental for tea cultivation in Uji Area where most of the tea plantations only conduct harvest once a year in the period of late April to late May. From this analysis it can be concluded that fluctuations in the average mean air temperature will directly affect the tea plants phenology. Therefore further analysis using the average mean air temperature to develop bio-climatic indicators such as Heliothermal Index would be necessary to identify the detailed effects on the tea cultivation process.

3.1.2 Average Minimum Air Temperature

Analysis from the same climatic data set on the average minimum air temperature in the period of 2002 to 2010 showed in table 3.2 indicated that there are increasing occurrences in the temperature fluctuations especially in the period of late February (2c), early March (3a), mid March (3b), and mid April (4b) to late April (4c). Shown in figure 3.4 it is also evident that there is a tendency for the average minimum air temperature to increase with increase in average mean air temperature.

	1a	1b	1c	2a	2b	2c	3a	3b	3c	4a	4b	4c	5a	Mean	Median	Std Dev
2002	0	-2.9	-0.3	-0.4	-1.8	-0.3	0.2	0.1	4.3	4.6	7.6	6.4	12.4	2.30	0.1	4.43
2003	-1	2.3	0.2	-0.5	-1.2	2.6	0.7	3.1	3.3	7	7.8	11.7	14.1	3.85	2.6	4.90
2004	0.4	0.7	-1.8	-1	-0.8	2.3	0	2.1	4.6	3.8	10.6	7.6	13	3.19	2.1	4.63
2005	-0.4	0.6	-0.4	0.7	1.3	-1.4	0.7	1.1	2.9	5	7.6	9.3	11.8	2.98	1.1	4.16
2006	-1.5	0.7	-0.9	-0.6	0.9	1.5	1.7	1	1.9	4.7	8.9	7.4	13	2.98	1.5	4.32
2007	0.9	-0.3	-0.4	0.1	0.6	0.8	1.5	-0.5	3.2	4.3	6.6	8.8	12.5	2.93	0.9	4.07
2008	0.5	0.3	0.7	-0.6	-0.8	-0.9	0.4	5.4	4.4	5.6	9.8	8.9	12.3	3.54	0.7	4.53
2009	1.4	-0.8	1.1	-0.4	1.5	3.3	3.1	2.8	2.3	3.6	10.3	7.2	12.5	3.68	2.8	3.98
2010	0.5	-1.1	0.4	0.8	0.4	6.5	5.7	3.3	2.9	5.8	8.8	7.7	11.1	4.06	3.3	3.83
Mean	0.089	-0.056	-0.156	-0.211	0.011	1.600	1.556	2.044	3.311	4.933	8.667	8.333	12.522			
Std Err	0.307	0.487	0.292	0.205	0.395	0.816	0.608	0.610	0.316	0.356	0.457	0.522	0.278			
Median	0.4	0.3	-0.3	-0.4	0.4	1.5	0.7	2.1	3.2	4.7	8.8	7.7	12.5			
Mode	0.5	0.7	-0.4	-0.4	-0.8	#N/A	0.7	#N/A	2.9	#N/A	7.6	#N/A	13			
Std Dev	0.920	1.460	0.876	0.615	1.185	2.447	1.825	1.829	0.948	1.067	1.372	1.567	0.833			
Smpl Var	0.846	2.130	0.768	0.379	1.404	5.988	3.330	3.345	0.899	1.138	1.883	2.455	0.694			
Kurtosis	-0.347	1.249	0.318	-0.486	-1.551	0.805	2.983	-0.047	-1.192	0.395	-1.235	1.932	1.354			
Skewness	-0.509	-0.533	-0.494	0.810	-0.230	0.811	1.741	0.409	0.078	0.748	0.072	1.220	0.244			
Range	2.9	5.2	2.9	1.8	3.3	7.9	5.7	5.9	2.7	3.4	4	5.3	3			
Min	-1.5	-2.9	-1.8	-1	-1.8	-1.4	0	-0.5	1.9	3.6	6.6	6.4	11.1			
Max	1.4	2.3	1.1	0.8	1.5	6.5	5.7	5.4	4.6	7	10.6	11.7	14.1			
Sum	0.8	-0.5	-1.4	-1.9	0.1	14.4	14	18.4	29.8	44.4	78	75	112.7			
Count	9	9	9	9	9	9	9	9	9	9	9	9	9			

Source: Kyoto Prefecture Tea Industry Research, 2015

Table 3.2 Average Minimum Air Temperature (ºC) Between Early January to Early May (2002-2010)

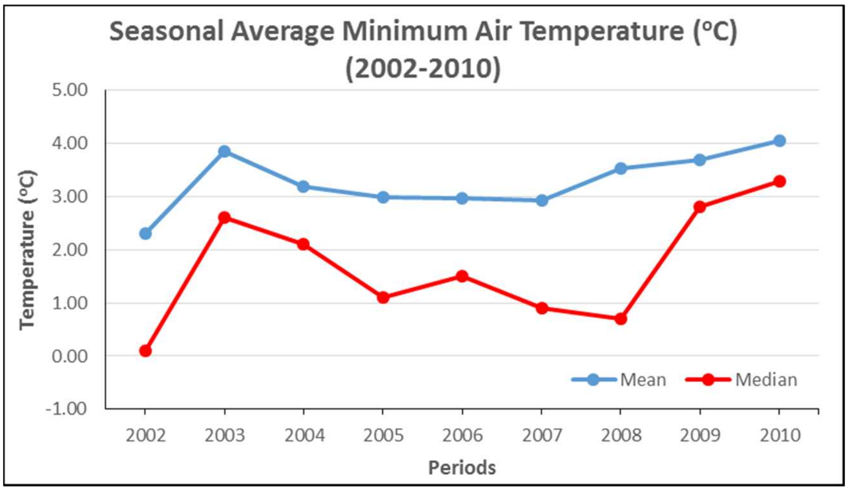
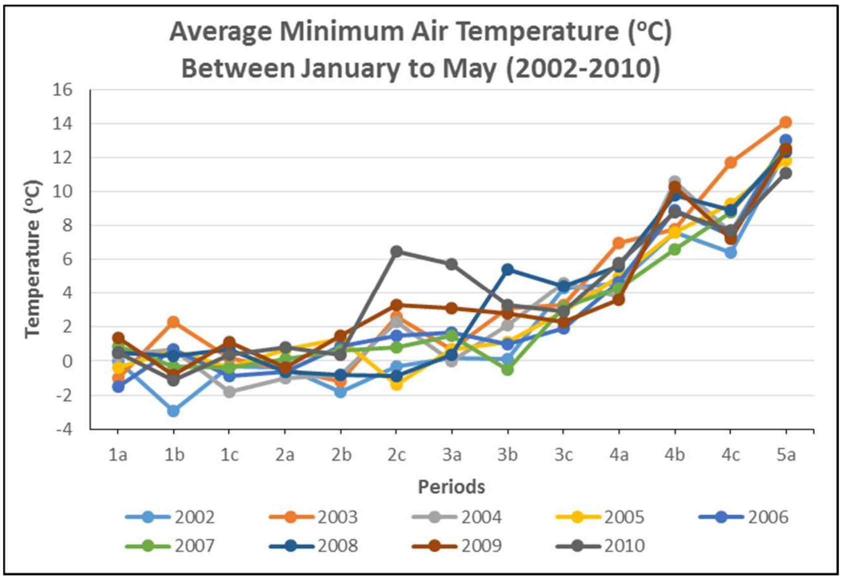


Figure 3.4 Seasonal Average Minimum Air Temperature (ºC) Between Early January to Early May (2002-2010)



Source: Kyoto Prefecture Tea Industry Research, 2015

Figure 3.5 Average Minimum Air Temperature (°C) Between Early January to Early May (2002-2010)

The period of late February (2c) to mid March (3b) is critical for leaf bud growth as during this period the leaf buds are beginning to appear and susceptible to drastic changes in the micro-climatic condition. The period of mid April (4b) to late April (4c) also very critical as the leaf maturation occurred in this period. Sudden drop in the ground temperature to below freezing point would trigger frost event which freezes water vapour from humid air is especially abundant during the warm spring season. The occurring frost event would damage leaf buds and also affect the growth of the existing leaves whereas the sudden changes would alter the composition of leaf fiber. The damages sustained from a sudden drop in the average minimum air temperature would be disastrous to some extent, such as in the case of frost event where the excessively frosted tea leaf buds tend to wither, resulting in loss of the harvest yield.

As previously mentioned, increasing average minimum air temperature might bring benefit with early leaf growth, however the temperature drop that occurred after the warming period would be harmful for the tea leaves. Although the average minimum air temperature could be utilized to identify low temperature and frost events, cool temperature is regarded beneficial for tea cultivation process as it slows down the plant metabolism and contributes to better leaf taste. Based on this analysis, the average minimum air temperature data would be further analysed and calculated into Cool Night Index.

3.1.3 Average Maximum Air Temperature

Similarly with the average minimum air temperature, the same analyses are also conducted for average maximum air temperature data sets shown in table 3.3. From the data sets it could be observed that there are identifiable temperature fluctuations on the period of mid February (2b), late February (2c), mid March (3b), mid April (4b and late April (4c); whereas the fluctuations showed the tendencies towards sudden temperature increase (figure 3.6).

	1a	1b	1c	2a	2b	2c	3a	3b	3c	4a	4b	4c	5a	Mean	Median	Std Dev
2002	7.9	5.4	7.7	8.4	9	11.6	9.9	13.6	16.2	20.3	21.9	19.8	23.2	13.454	11.6	6.133
2003	8	12	8.2	10.4	8.3	13.7	12.8	18.3	16.9	21.4	21.4	22.3	23.5	15.169	13.7	5.762
2004	11.6	8.1	8.2	9.6	14	14.9	11	17.2	16.4	19.7	25	23.2	25.3	15.708	14.9	6.105
2005	8.6	8.9	9.4	8.6	9.4	9.5	13	12.4	14.2	20.9	21.1	25.4	24.8	14.323	12.4	6.415
2006	7.6	9.9	8.2	7.9	10.7	11.9	12.5	11.2	14.4	16.4	17.7	19.4	25.2	13.308	11.9	5.180
2007	10.1	10.6	11.2	11.8	12	14.1	15.3	10.2	17.6	16.8	20.6	23.3	25	15.277	14.1	5.085
2008	11.7	8.9	6.9	7.6	8.8	10.4	12.4	18.2	17.4	18.8	20.1	24.7	26.4	14.792	12.4	6.550
2009	10	9.1	10.9	11.4	12.7	11.9	13.2	16.9	15.7	20	25.5	20.8	24.7	15.600	13.2	5.554
2010	9.3	10.1	10.3	10.4	9.6	17.3	12.4	17.1	12.8	19.7	17.7	18.9	26.8	14.800	12.8	5.272
Mean	9.422	9.222	9.000	9.567	10.500	12.811	12.500	15.011	15.733	19.333	21.222	21.978	24.989			
Std Err	0.515	0.612	0.504	0.509	0.660	0.807	0.496	1.055	0.540	0.573	0.909	0.788	0.390			
Median	9.3	9.1	8.2	9.6	9.6	11.9	12.5	16.9	16.2	19.7	21.1	22.3	25			
Mode	#N/A	8.9	8.2	10.4	#N/A	11.9	12.4	#N/A	#N/A	19.7	17.7	#N/A	#N/A			
Std Dev	1.544	1.835	1.513	1.528	1.981	2.420	1.487	3.166	1.621	1.720	2.728	2.364	1.170			
Smpl Var	2.384	3.367	2.290	2.335	3.923	5.859	2.212	10.024	2.628	2.960	7.442	5.589	1.369			
Kurtosis	-1.242	2.021	-1.360	-1.499	-0.785	0.001	1.586	-1.713	-0.510	-0.271	-0.469	-1.522	-0.296			
Skewness	0.421	-0.840	0.314	0.168	0.743	0.553	0.073	-0.471	-0.683	-0.874	0.344	0.075	-0.027			
Range	4.1	6.6	4.3	4.2	5.7	7.8	5.4	8.1	4.8	5	7.8	6.5	3.6			
Min	7.6	5.4	6.9	7.6	8.3	9.5	9.9	10.2	12.8	16.4	17.7	18.9	23.2			
Max	11.7	12	11.2	11.8	14	17.3	15.3	18.3	17.6	21.4	25.5	25.4	26.8			
Sum	84.8	83	81	86.1	94.5	115.3	112.5	135.1	141.6	174	191	197.8	224.9			
Count	9	9	9	9	9	9	9	9	9	9	9	9	9			

Source: Kyoto Prefecture Tea Industry Research, 2015

Table 3.3 Average Maximum Air Temperature (^{o}C) Between Early January to Early May (2002-2010)

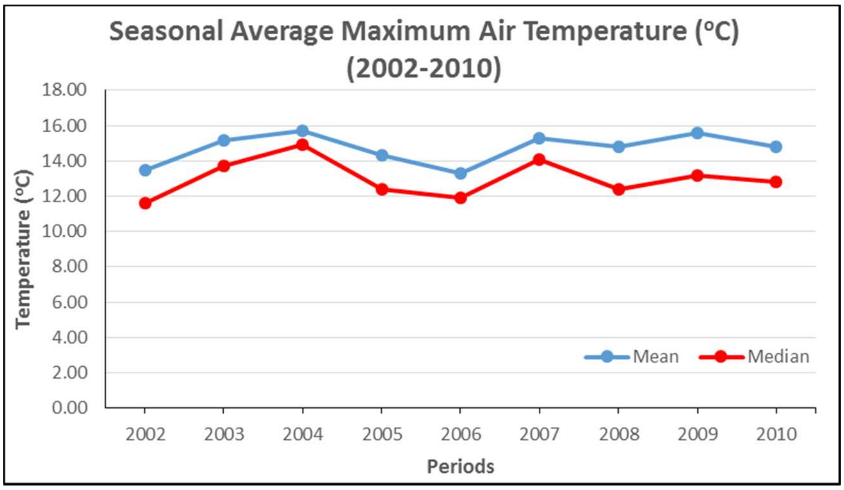
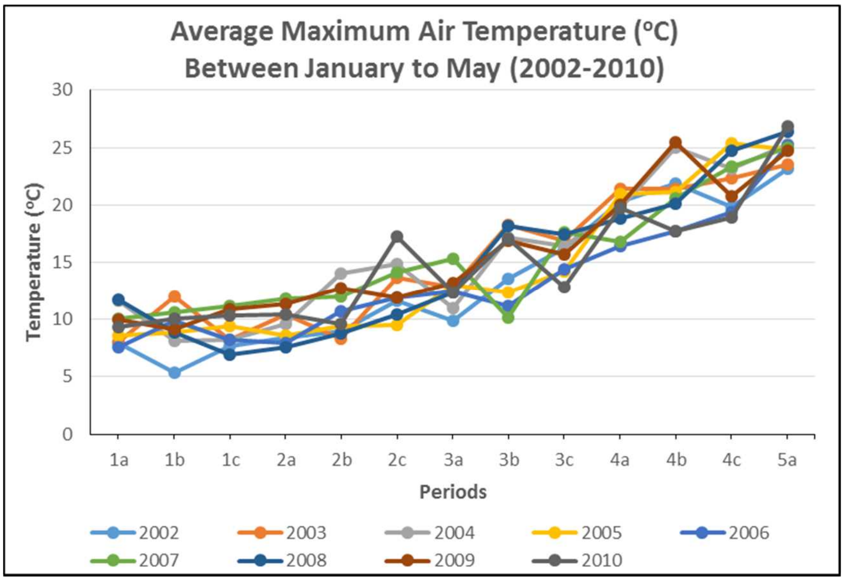


Figure 3.6 Seasonal Average Maximum Air Temperature (^{o}C) Between Early January to Early May (2002-2010)



Source: Kyoto Prefecture Tea Industry Research, 2015

Figure 3.7 Average Maximum Air Temperature (ºC) Between Early January to Early May (2002-2010)

From these analyses it can be concluded that there are indications of early warming which occurred around mid February (2b) to late February (2c) have triggered early leaf growth. Although this warming might be beneficial for leaf growth, the data sets on average minimum temperature (table 3.2) revealed that there were temperature drops in mid March (3b) which lead to frost events and low temperature damages. Further discussions on the average maximum air temperature in the tea cultivation as a bio-climatic indicator, will be discussed on chapter 4.

3.1.4 Precipitation

Based on social survey and observation conducted to tea growers in Uji Area, it was found that the precipitation which occurred during the first flush tea cultivation period especially between late April (4c) to early May (5a), is crucial for the growth of tea plants, as it directly affects the leaf growth conditions. Showed in table 3.4 it could be observed that there were identifiable changes of precipitation in early April (4a) and late April (4c). From figure 3.8 it could also be identified that there is evidence of increasing precipitation during first flush tea cultivation period.

Year	1a	1b	1c	2a	2b	2c	3a	3b	3c	4a	4b	4c	5a	Total	Mean	Median	Std Dev
2002	47.60	15.30	69.30	37.00	1.00	44.20	45.30	12.40	29.00	2.50	21.70	23.90	36.50	385.70	29.669	29.0	19.600
2003	29.00	5.70	74.00	15.00	34.40	22.90	72.90	21.50	37.20	56.30	25.20	88.60	64.50	547.20	42.092	34.4	26.180
2004	0.60	23.30	0.60	9.10	4.00	51.70	4.60	24.20	78.60	40.50	58.60	19.10	76.70	391.60	30.123	23.3	28.322
2005	13.10	27.10	2.40	17.10	46.60	6.90	14.00	39.90	44.40	2.60	34.70	2.60	64.30	315.70	24.285	17.1	20.142
2006	1.00	36.80	5.10	40.50	40.20	34.80	48.70	51.00	32.00	65.20	64.40	2.60	55.10	477.40	36.723	40.2	21.899
2007	11.80	11.00	0.30	8.10	43.60	23.40	11.20	13.30	44.10	9.80	27.40	13.20	53.30	270.50	20.808	13.2	16.470
2008	1.30	22.60	29.50	33.70	7.70	33.50	16.70	59.40	39.90	76.40	73.80	15.00	26.30	435.80	33.523	29.5	23.611
2009	10.30	14.70	70.80	13.40	53.60	55.30	39.50	73.80	23.20	20.20	35.40	55.70	43.00	508.90	39.146	39.5	21.759
2010	5.50	3.30	29.80	35.60	45.30	70.20	39.70	51.90	72.10	87.40	60.40	121.20	22.00	644.40	49.569	45.3	33.119
Mean	13.356	17.756	31.311	23.278	30.711	38.1	32.511	38.6	44.5	40.1	44.622	37.989	49.078				
Std Err	5.2064	3.5737	10.71	4.3796	6.8564	6.4561	7.438	7.2938	6.2908	10.917	6.5294	13.945	6.162				
Median	10.3	15.3	29.5	17.1	40.2	34.8	39.5	39.9	39.9	40.5	35.4	19.1	53.3				
Mode	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	2.6	#N/A				
Std Dev	15.619	10.721	32.129	13.139	20.569	19.368	22.314	21.881	18.873	32.752	19.588	41.836	18.486				
Smpl Var	243.96	114.94	1032.3	172.62	423.09	375.13	497.91	478.79	356.17	1072.7	383.7	1750.3	341.73				
Kurtosis	2.224	-0.361	-1.852	-2.168	-1.597	-0.321	-0.515	-1.315	0.1237	-1.735	-1.84	0.549	-1.068				
Skewness	1.5925	0.376	0.4517	0.183	-0.652	0.0822	0.4515	0.2256	1.0723	0.147	0.2779	1.2857	-0.135				
Range	47	33.5	73.7	32.4	52.6	63.3	68.3	61.4	55.4	84.9	52.1	118.6	54.7				
Min	0.6	3.3	0.3	8.1	1	6.9	4.6	12.4	23.2	2.5	21.7	2.6	22				
Max	47.6	36.8	74	40.5	53.6	70.2	72.9	73.8	78.6	87.4	73.8	121.2	76.7				
Sum	120.2	159.8	281.8	209.5	276.4	342.9	292.6	347.4	400.5	360.9	401.6	341.9	441.7				
Count	9	9	9	9	9	9	9	9	9	9	9	9	9				

Source: Kyoto Prefecture Tea Industry Research, 2015

Table 3.4 Precipitation (mm) Between Early January to Early May (2002-2014)

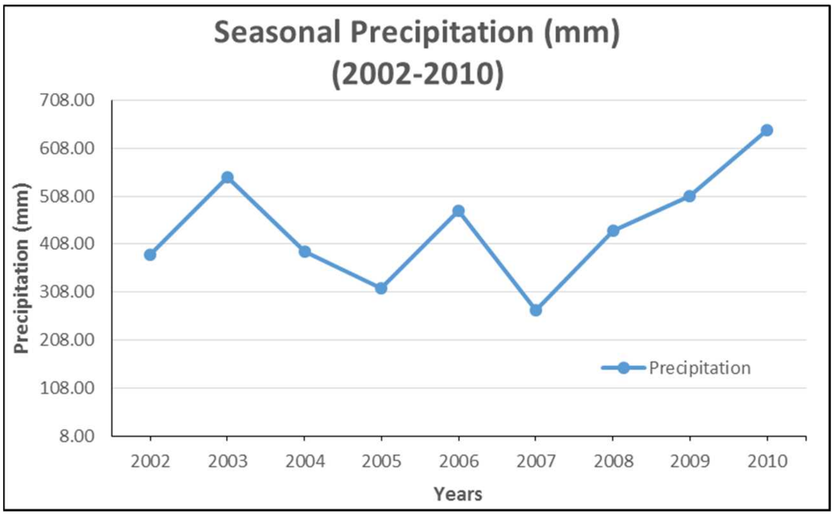
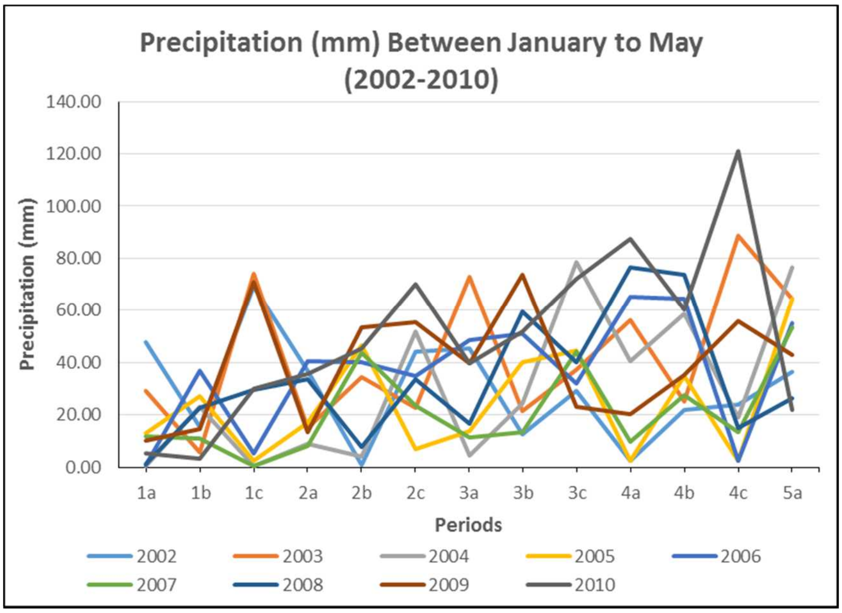


Figure 3.8 Seasonal Precipitation (mm) Between Early January to Early May (2002-2010)



Source: Kyoto Prefecture Tea Industry Research, 2015

Figure 3.9 Precipitation (mm) Between Early January to Early May (2002-2010)

Sudden fluctuation in the precipitation rates especially in the form of excessive rain would pose direct threats to the tea plantation, as high volume of water would wash away the important soil elements obtained from the fertilizer. It is also observed that there is increasing risk of flooding for the tea plantations in Uji Area which are situated around the river. From analyses it could be revealed that there are significant fluctuations in the total precipitation within the first flush harvest period, which indicates that occurrences of short period excessive rainfall are highly likely.

3.1.5 Humidity

Humidity is considered an important factor in general tea cultivation and, therefore, the humidity factor is also analysed in this research as shown in table 3.5. Higher humidity would increase the risk for pest and fungus damages in the tea plants. In general tea plants prefer cultivation condition with high humidity level around 70 to 80 percent. Observations from the data sets have revealed that the humidity level is slowly decreasing until late April (4c) before increasing again. Drop in the humidity level is also observed in early April (4a). From further statistical analyses result, shown in table 3.10 it could be observed that there is an apparent increase in the seasonal average humidity value.

Year	1a	1b	1c	2a	2b	2c	3a	3b	3c	4a	4b	4c	5a	Mean	Median	Std Dev
2002	70.50	61.20	78.70	76.40	67.70	72.60	69.10	67.30	67.90	66.00	63.00	67.10	76.00	69.500	67.9	5.205
2003	68.50	76.60	69.20	76.10	72.10	72.00	69.40	65.10	71.30	66.00	71.10	72.00	77.10	71.269	71.3	3.751
2004	82.40	81.90	72.90	72.30	76.40	79.60	75.20	74.70	78.10	73.30	74.50	69.80	78.80	76.146	75.2	3.813
2005	76.40	73.50	72.00	70.90	75.90	69.30	71.30	73.90	72.10	65.80	67.00	61.70	69.80	70.738	71.3	4.114
2006	71.90	75.10	75.00	73.80	75.80	76.00	76.90	74.10	70.50	69.60	73.60	68.10	73.80	73.400	73.8	2.650
2007	78.30	78.50	74.00	71.70	73.20	71.30	68.70	68.30	75.30	70.10	67.40	70.60	75.30	72.515	71.7	3.624
2008	77.40	78.10	81.50	82.10	75.10	74.40	75.40	73.70	73.20	72.40	78.20	71.20	70.10	75.600	75.1	3.700
2009	80.40	76.20	79.00	76.40	77.40	79.90	75.70	74.90	69.10	69.20	67.70	70.10	67.50	74.115	75.7	4.749
2010	71.80	74.60	82.80	79.10	79.60	82.00	88.20	75.00	77.80	71.80	78.20	71.30	69.90	77.085	77.8	5.354
Mean	75.289	75.078	76.122	75.422	74.8	75.233	74.433	71.889	72.811	69.356	71.189	69.1	73.144			
Std Err	1.5992	1.9231	1.5343	1.2201	1.1482	1.4719	2.0248	1.285	1.2089	0.9618	1.7726	1.0617	1.3108			
Median	76.4	76.2	75	76.1	75.8	74.4	75.2	73.9	72.1	69.6	71.1	70.1	73.8			
Mode	#N/A	#N/A	#N/A	76.4	#N/A	#N/A	#N/A	#N/A	#N/A	66	78.2	#N/A	#N/A			
Std Dev	4.7975	5.7693	4.6029	3.6602	3.4446	4.4156	6.0745	3.855	3.6268	2.8854	5.3178	3.1851	3.9323			
Smpl Var	23.016	33.284	21.187	13.397	11.865	19.498	36.9	14.861	13.154	8.3253	28.279	10.145	15.463			
Kurtosis	-1.399	4.9769	-1.199	-0.265	1.4914	-1.35	3.0194	-0.905	-1.095	-1.567	-1.173	3.589	-1.554			
Skewness	0.0394	-1.914	0.0793	0.5603	-0.972	0.3226	1.5265	-0.985	0.3432	-0.106	0.0215	-1.816	-0.009			
Range	13.9	20.7	13.6	11.2	11.9	12.7	19.5	9.9	10.2	7.5	15.2	10.3	11.3			
Min	68.5	61.2	69.2	70.9	67.7	69.3	68.7	65.1	67.9	65.8	63	61.7	67.5			
Max	82.4	81.9	82.8	82.1	79.6	82	88.2	75	78.1	73.3	78.2	72	78.8			
Sum	677.6	675.7	685.1	678.8	673.2	677.1	669.9	647	655.3	624.2	640.7	621.9	658.3			
Count	9	9	9	9	9	9	9	9	9	9	9	9	9			

Source: Kyoto Prefecture Tea Industry Research, 2015

Table 3.5 Humidity (%) Between Early January to Early May (2002-2010)

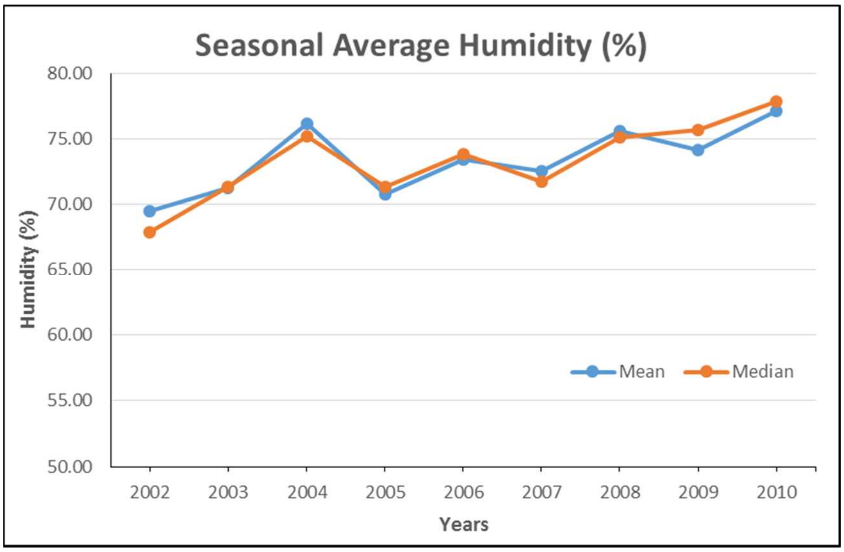
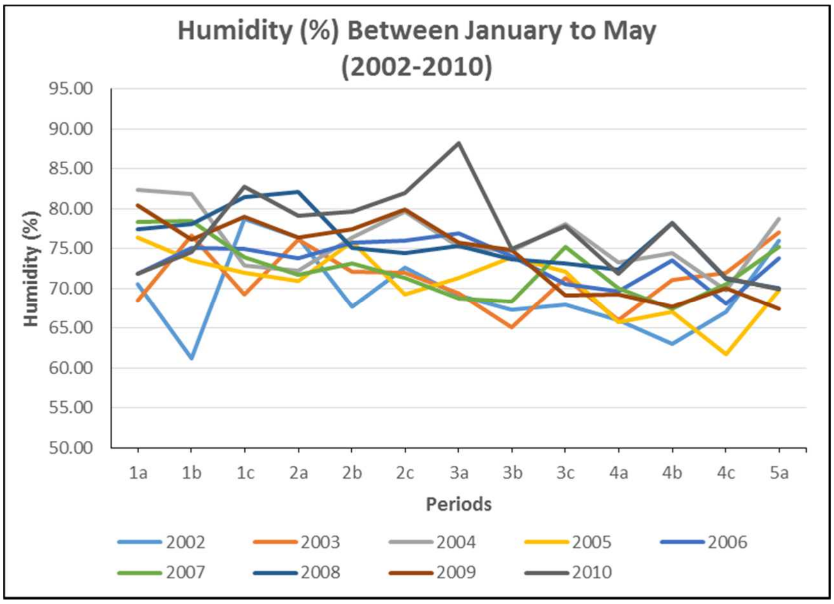


Figure 3.10 Seasonal Average Humidity (%) Between Early January to Early May (2002-2010)



Source: Kyoto Prefecture Tea Industry Research, 2015

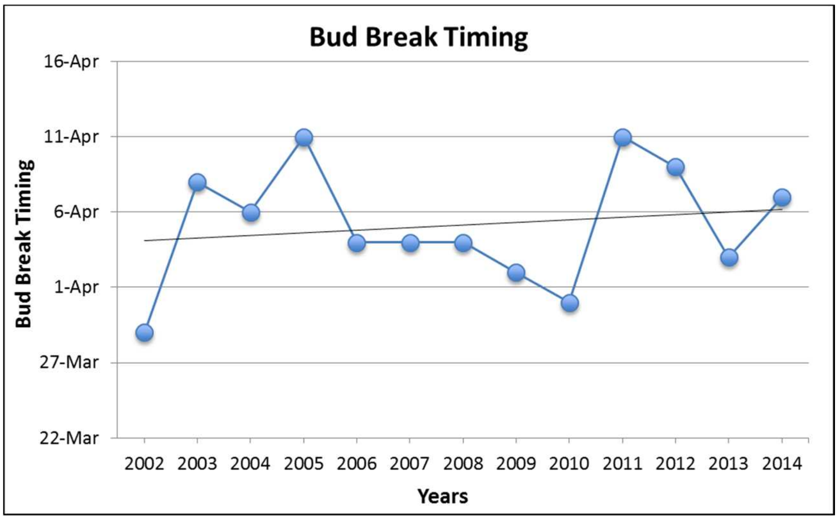
Figure 3.11 Humidity (%) Between Early January to Early May (2002-2010)

Observations from the data sets have revealed that the humidity level is slowly dropping throughout the first flush cultivation period, in parallel with the temperature increase.

3.1.6 Bud Break and Harvest Period

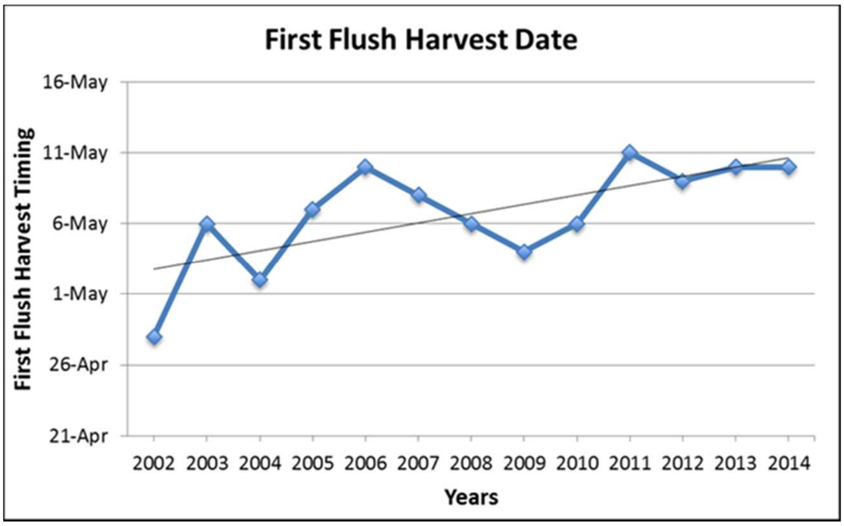
From the obtained Uji Area tea growth data there are some indications that the leaf bud break has been occurring later (figure 3.12) which corresponds to the tea leaf harvest period (figure 3.13). From the previous analyses on average mean air temperature (table 3.1), average minimum air temperature (table 3.2), average maximum air temperature (table 3.3) and humidity (table 3.5), some correlation could be observed.

Based on observations, bud break timing usually falls in the period where the humidity level is in low value which is in the period around late early April (4a). The air temperature analyses also showed a lower temperature trend on late March (3c) the period where bud break started, thus in the following period (early April (4a)) lower temperature trends are also still evident except for the average maximum temperature which showed slight increase in the temperature trends. These lower temperature trends have affected the tea plants bud break as well as the new leaf growth, which impacted on the leaf harvest date.



Source: Kyoto Prefecture Tea Industry Research, 2015

Figure 3.12 Recorded Bud Break Timing from 2002-2014



Source: Kyoto Prefecture Tea Industry Research, 2015

Figure 3.13 Recorded First Flush Harvest Date from 2002-2014

3.1.7 Soil and Topography

Based on social survey it was also found that changes in the climatic condition affect the tea plantations differently depending on its location and topography. Tea plantations which are located around the river have experienced flooding and soil run-off during excessive rain. More over these tea plantations are also more susceptible towards drought, however because of its close proximity with water sources plant watering is possible if deemed necessary. The tea plantations in the hill side are more resilient towards dry season and prolonged drought as clay soil have a better moisture retention, although from the social survey tea growers in the hill areas have mentioned an increase of pest problems in parallel with increasing temperature.

3.1.8 Recorded Climatic Data in Koyama-en and Shichimei-en

This research is using not only the data from Kyoto Prefecture Tea Industry Research, but also utilizing climatic data which are monitored and recorded in two different locations in Uji Area[5] (figure 3.14). From the two stations the recorded climatic data consist was conducted on five minutes interval for one year period in 2014. Following the calculation methods used by Kyoto Prefecture Tea Industry Research, the recorded data is averaged into three parts for every month. In total there were 10 data sets which were monitored and recorded on each station, whereas the data sets which are identical with the Kyoto Prefecture Tea Industry Research are shown in table 3.6 and table 3.7.

	Average Mean Air Temperature	Average Minimum Air Temperature	Average Maximum Air Temperature	Precipitation	Humidity
1a	4.54	0.47	9.25	33.38	77.78
1b	2.98	-1.47	8.05	3.00	74.92
1c	5.28	0.10	10.60	19.12	77.10
2a	4.77	1.22	9.16	21.54	78.75
2b	3.27	-0.25	7.40	28.00	73.25
2c	6.47	1.60	12.14	8.53	72.11
3a	5.60	1.22	9.72	18.00	74.37
3b	8.79	2.92	14.52	42.70	73.20
3c	11.60	5.86	17.11	68.80	71.56
4a	12.00	5.07	19.67	12.78	67.42
4b	13.45	5.96	20.88	8.82	57.02
4c	16.25	10.11	23.43	30.88	68.32
5a	17.52	10.50	25.46	0.25	62.46

Table 3.6 Recorded Climatic Data from Early January (1a) to Early May (5a) on Koyama-en (2014)

[5] Cooperating tea plantations are Koyama-en「丸久小山園」 and Shichimei-en「堀井七茗園」, the field informatics stations were set up by Monte Cassim's Sustainability Science laboratory, financed largely by the O-RID research grant, with logistical support from Ujicha Cooperative「京都府茶協同組合」.

	Average Mean Air Temperature	Average Minimum Air Temperature	Average Maximum Air Temperature	Precipitation	Humidity
1a	3.90	-0.32	8.98	30.69	82.44
1b	2.27	-2.34	7.83	1.75	80.16
1c	4.54	-0.75	10.35	15.56	81.90
2a	3.28	1.63	7.10	10.40	77.49
2b	4.94	-0.52	7.58	23.00	70.38
2c	5.52	2.04	13.08	0.00	73.11
3a	9.34	-0.11	9.72	18.40	78.41
3b	9.79	4.26	14.52	42.00	67.32
3c	11.53	6.11	17.11	62.60	69.03
4a	11.95	5.47	19.67	10.80	63.97
4b	13.32	6.41	20.88	7.20	54.61
4c	16.08	10.26	23.43	33.20	66.88
5a	17.35	10.28	25.57	1.40	60.65

Table 3.7 Recorded Climatic Data from Early January (1a) to Early May (5a) on Shichimei-en (2014)

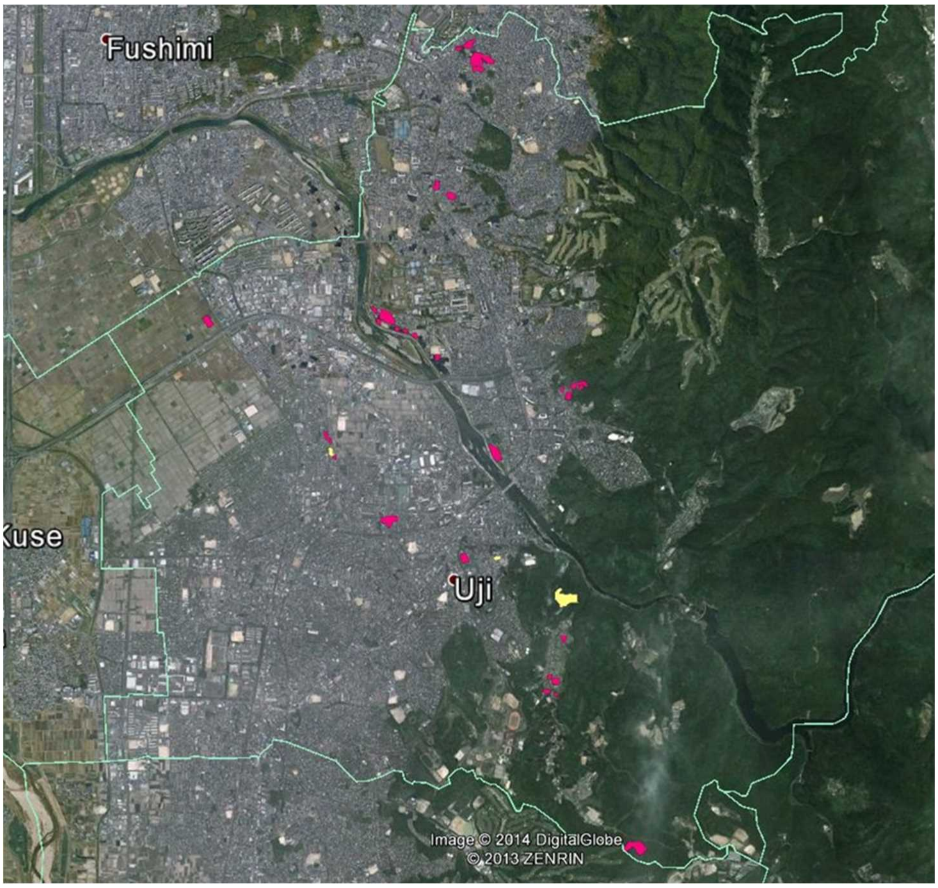
3.2 Agriculture Practices Elements

Changes in the natural environmental elements would directly affect the second of the terroir elements (agricultural practices) as the tea cultivation in Uji Area utilizes many traditional cultivation practices in the process. In order to obtain information on the tea cultivation practices, social surveys and observations are necessary to fully comprehend how climatic changes have directly affected the tea cultivation process.

3.2.1 Social Surveys and Observations

Based on demographic data obtained from Kyoto Prefecture (2013), there are currently 113 active tea growers and 21 registered tea plantations in Uji Area. As part of the research approach to further understand the climate change effect towards Uji Tea cultivation, social surveys and observations were conducted targeting tea growers as well as their tea plantations between late 2013 to early 2014.

Although currently there are 113 active tea growers in Uji Area, this number is actually different from what it appears to represent. In each tea grower's household, there are at least two to four individual who are registered as a tea grower. However, the active tea growers who work full time in the tea plantation are usually only one or two. Thereby translating the actual number of active tea growers to only half or one third from the registered number. Shown in figure 3.14 the location of social surveys and observations are indicated with the areas in red, while areas in yellow indicate locations of the weather station.



Source: Google Earth, 2014

Figure 3.14 Location of Social Survey and Observation, and Location of Weather Stations

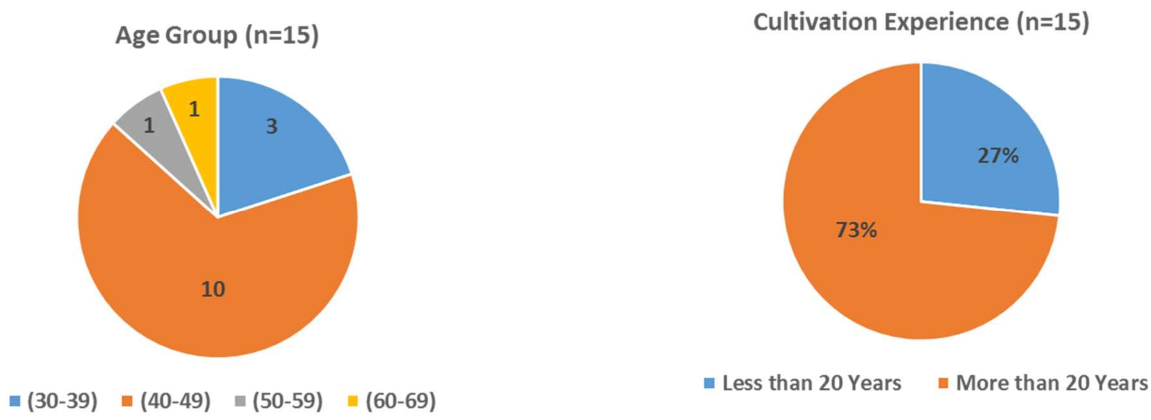


Figure 3.15 General Information of the Interviewed Tea Growers

There were 15 tea growers who cooperated in the social surveys and observations. As mentioned previously there were seven main guiding questions in the interviews. In this chapter the focus of the analyses are on: 1) Demographic Information; 2) Agriculture Knowledge; 3) Terroir Comprehension; 4) Opinion on Climate Change; and 5) Seasonal Cultivation Process.

Showed in figure 3.15 from the total 15 tea growers, age group of the interviewed growers consist of 3 growers in the age group 30-39 years; 10 growers in the age group 40-49 years; 1 growers in the age group 50-59 years; and 1 growers in the age group 60-69 years. Among them 73 percent has been cultivating tea for more than 20 years, while 27 percent in between 15 to 20 years of experience.

The percentage on cultivation experience corresponds to the questions about terroir comprehension (figure 3.16), where 80 percent of the respondents said they obtained their knowledge on tea cultivation from their family, while the remaining 20 percent acquired cultivation knowledge through self-experience as well as information sharing from fellow tea growers. All of tea growers also mentioned that they have been involved (directly or indirectly) in their family's tea plantation since a young age. This concludes that there is evidence of implicit inherited knowledge being passed down through generations of tea growers

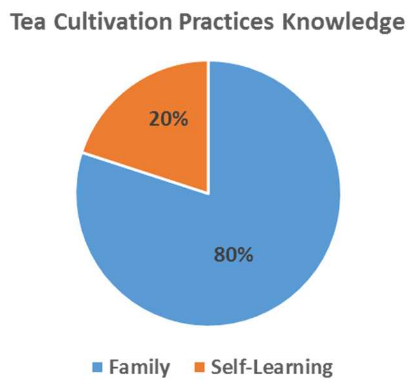


Figure 3.16 Tea Cultivation Practices Knowledge

From further analysis on the topic of terroir comprehension, it could be observed that each the tea growers has their own special cultivation methods which are not revealed to other tea growers. Some of the questions were answered cautiously by the tea growers, whereas the immediate reply to some questions was that they were cultivation secrets. Younger tea growers are more open about their practices while the senior tea growers were more careful in constructing their answers.

Analysis from the interview answers were then cross referenced with climatic data analysis (figure 3.17) to identify the correlations between environmental conditions with the tea cultivation process analysis. From this analysis, the climatic factors which affect the decisions on cultivation intervention and timing could be recognized and, thus, important bio-climatic indicators could also be identified from these results.

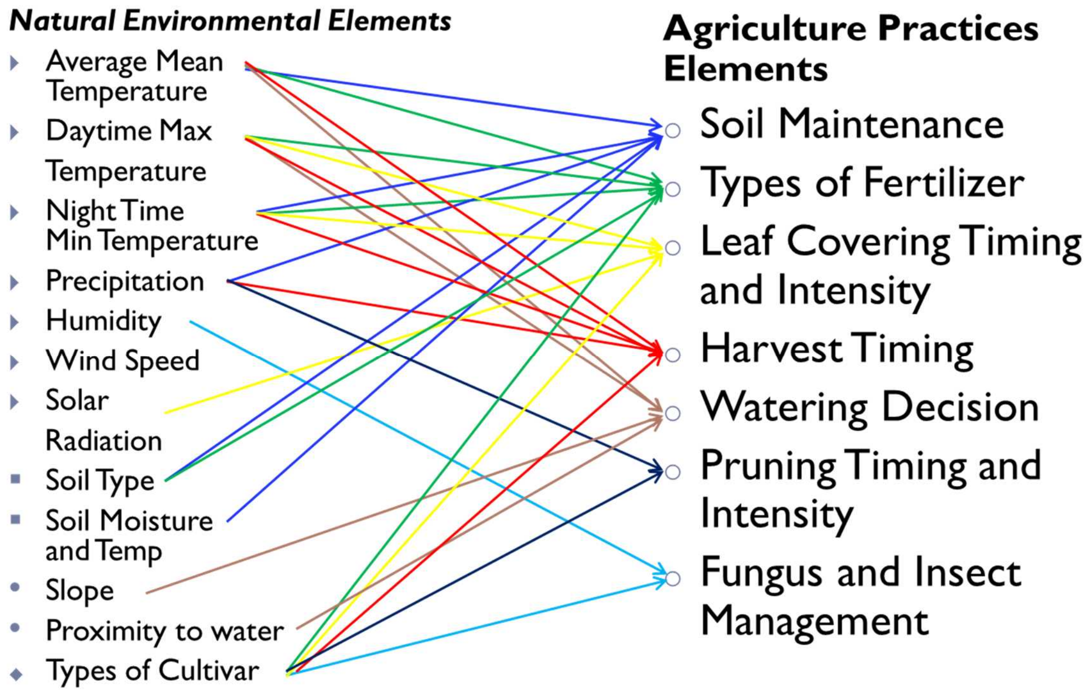


Figure 3.17 Cross References between Environmental Data with Social Survey and Observation Data

3.2.2 Perceived Climatic Changes

The on-going changes in the climatic conditions of Uji Area have clearly shown that there are increasing trends of extreme weather events. These events undoubtedly have affected the tea cultivation process cycle, because tea plants are sensitive towards changes in the micro-climatic conditions especially to temperature fluctuations. In order to maintain the renowned characteristic of Uji Tea, young tea leaves need to be plucked before the leaf fiber becomes too hard and there is a growing awareness among tea growers that exposure to extreme fluctuations of mean air temperature will accelerate the hardening process of tea leaf fiber, which would ultimately influence the taste of the tea products.

Based on Kyoto Prefecture Tea Industry Research (2012) findings, in the past years the observed changes in Uji Area are: 1) sudden drop in temperature during spring season; 2) higher temperature during fall season; 3) changes in quantity and period of rainy season; 4) longer period of drought; 5) diminishing morning fog; which then lead to diminish the characteristics of high quality tea.

Social surveys conducted inside Uji Area tea grower's community revealed that the extreme climatic events have becoming more frequent over the past ten years. In this survey from 15 tea growers' respondents, the percentage extent to which climate change is perceived to affect the cultivation processes could be seen in figure 3.18, where 36 percent of the effect is seen to be caused by temperature fluctuations, 32 percent is drought, 18 percent is because of frost event and 14 percent is caused by excessive rainfall (Ashardiono and Cassim, 2015).

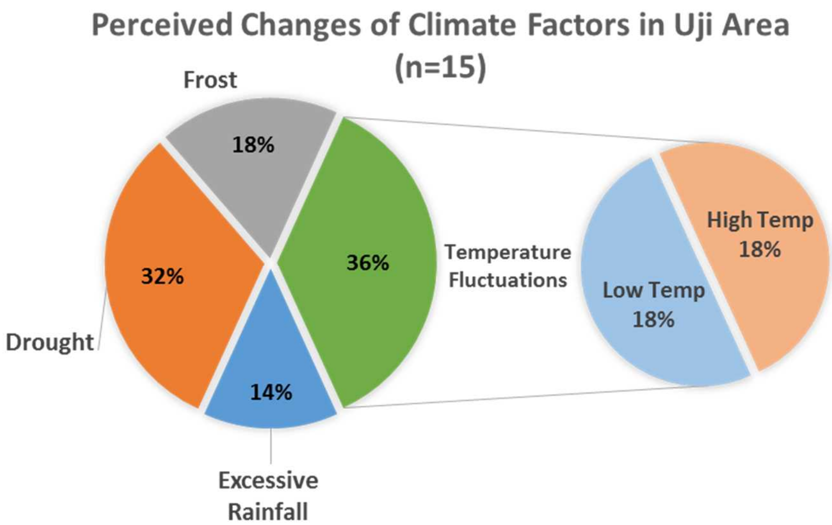


Figure 3.18 Perceived Changes of Climatic Factors in Uji Area

The result of the social surveys and observations have reflected the findings from analysis conducted on average mean air temperature (table 3.1), average minimum air temperature (table 3.2), average maximum air temperature (3.3), precipitation (table 3.4) and humidity (table 3.5) in the previous discussion. These have showed that there are only slight differences between the perceived changes felt by the tea growers and the actual climatic changes that have occurred.

As a response to prevent frost damages which are prevalent in the period shown in figure 3.2, tea growers have utilized several tools such as frost fans and water sprinklers in their tea plantations. Tea growers also used the leaf covering earlier than usual as a method to prevent extensive damages caused by temperature drops. Frost event which occurred during appearance of leaf bud and during bud break period is one of the most critical damages faced by the tea growers and, therefore, some of the growers have been harvesting earlier than usual to prevent total loss of harvest yield. Corresponding to the result of this analysis, some of the tea growers have reported that there is an increase of temperature drop and frost events happening in the tea plantation on the hill side of Uji Area

Tea growers in Uji Area have mentioned that there is reduced volume of precipitation in the period when new leaf bud is growing (table 3.4) which according to them will affect tea plant growth especially in the period after harvesting where most of the tea plants are pruned. In the case of excessive rainfall, tea growers who own tea plantations situated along the river plains, or those which are located in low lands expressed concern on excessive rainfall which happened in Uji Area, where with high volume of precipitation, the excess water rapidly overflowed into the tea plantations. This temporary flooding has washed away important nutrients from the soil, and if the flood water is not quickly drained the excessive amount of water will damage the tea plant.

In contrast, during the summer season prolonged drought directly affected the plant growth and reduced the quality and quantity of next season's harvest, as the tea plant will not be in a healthy condition. In general Uji Area tea growers do not water the tea plantation, but as the drought period has become longer in addition with increasing occurrences of days with high temperature, they are forced to start watering the tea plantation or risk having a poor harvest in the next season. As previously mentioned tea plantations which are located in the hill side are stronger at withstanding drought compared with the other tea plantations.

Most of the tea growers are also utilizing the leaf cover during the mid-summer period to prevent leaf burn which is caused by high temperature. Warm temperature during fall season has also become an issue where instead dropping slowly, the temperature would suddenly drop at the end of the season causing abrupt cessation of tea plant growth. This has a negative impact on the plant, reducing the quality of the next season's harvest.

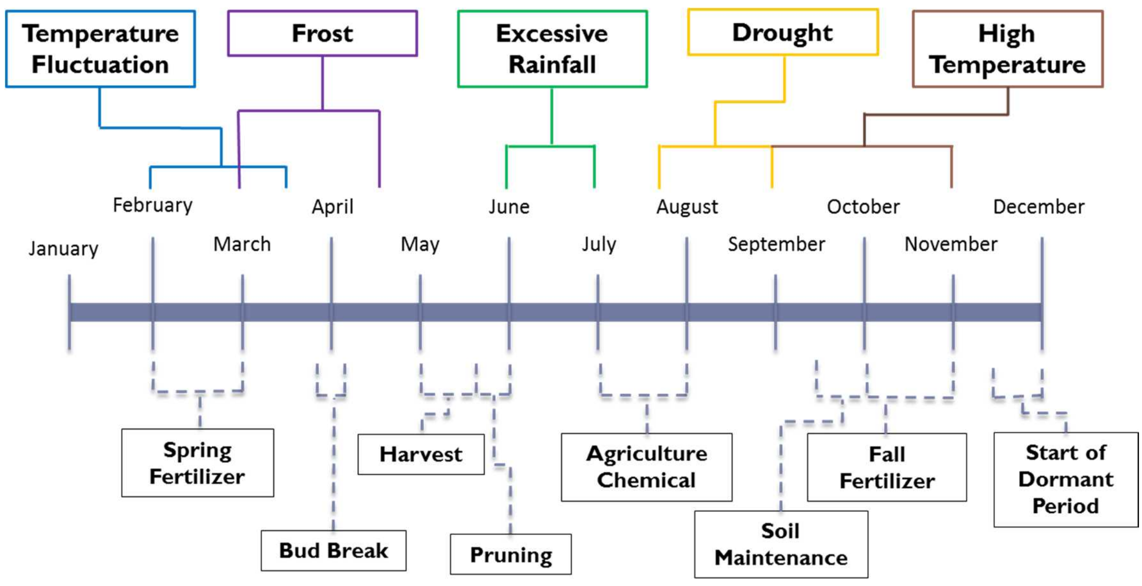


Figure 3.19 Climatic Changes in Uji Area Tea Cultivation Process

The correlation between climate change impacts towards the tea cultivation process in Uji Area can be clearly seen in figure 3.19 where temperature fluctuations and frost events occurring prior to first flush harvest is likely to directly affect the tea production quantity and value. This will be further discussed on chapter 4 and 5.

As previously explained, the tea growers in Uji Area have inherited tea cultivation knowledge as well as possessing detailed information about the natural environment conditions of their tea plantation, therefore they can identify any slight changes in the micro-climatic environment and can immediately predict the outcome from any of the occurring changes. In summary based on social survey from 15 tea growers it was found that the tea growers in Uji Area were able to develop new cultivation methods to adapt with the on-going climate change in order maintain the production yield, quality and values:

- Harvesting is conducted earlier (73%)
- Leaf covering is conducted earlier (86%)
- Application of thin leaf cover in the summer (60%)
- Utilization of watering system (50%)
- Utilization of frost fan system (33%)
- Deep soil treatment is conducted at later period (60%)

Although these methods are essential to maintain the sustainability of the tea cultivation process, in the near future the tea growers would not be able to cope with the rapid changes in the climatic conditions. From the social survey it could be understood that the tea growers utilize the leaf cover to prevent low temperature and frost damages, as well as to reduce high temperature damages during a prolonged drought season.

Several tea growers also conducted tea harvesting earlier than usual if they considered the tea leaf is ready for plucking.

In summary figure 3.20 illustrated how the changing climatic conditions have affected the terroir elements in Uji tea cultivation process, where they have not only affected the natural environmental elements, but has also directly affected the decision on conducting cultivation interventions. This last includes considerations of timing as well as selection of effective intervention types.

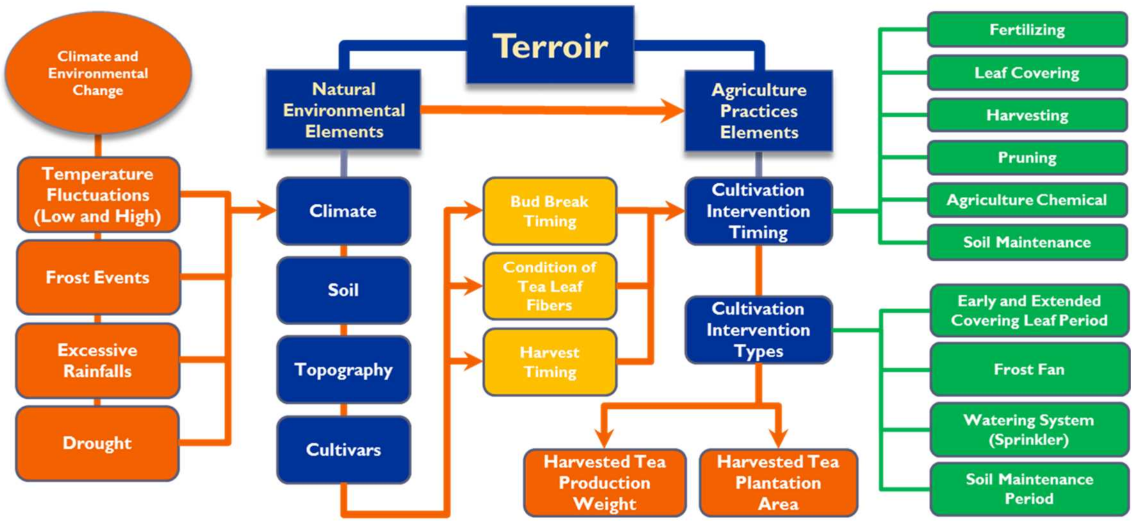


Figure 3.20 Climate Change Impact on Uji Tea Cultivation

3.2.3 Tea Production in Uji Area

Showed in table 3.6 is the statistical data of total tea production in Uji Area (1991-2013) obtained from Kyoto Prefecture (2015), where it can be observed that there is a declining trend of production weight, with several noticeable production drops occurring in 1995, 2002 and 2006. These drops in production were most likely caused by climatic conditions such as sudden extreme low temperature as well as frost event.

The total harvested plantation area have been decreasing in the past 20 years, mosty because of decrease in the number of tea plantations, except the sudden drop in 2002 were highly likely caused by climatic conditions. From the observation of tea production weight graph in figure 3.21 it can be seen that the graph became stable around 2009, which corresponds to the result of the social survey result which found that the tea growers have been extensively using new cultivation processes to minimize first flush tea leaf damage caused by low temperature and frost event.

Year	Total Weight (Kg)	Plantation Area (Ha)	Season Average Minimum Temperature	Season Average Maximum Temperature
1991	78,360.00	86.20		
1992	76,241.00	83.00		
1993	70,912.00	81.20		
1994	73,862.00	81.80		
1995	60,051.00	81.40		
1996	64,329.00	79.70		
1997	67,779.00	79.70		
1998	73,137.00	79.90		
1999	68,644.00	80.10		
2000	62,897.00	79.70		
2001	59,903.00	80.00		
2002	56,696.00	76.60	2.30	13.45
2003	63,767.00	77.20	3.85	15.17
2004	60,051.00	77.00	3.19	15.71
2005	61,477.00	81.40	2.98	14.32
2006	55,831.00	81.10	2.98	13.31
2007	61,904.00	80.90	2.93	15.28
2008	61,121.00	79.90	3.54	14.79
2009	64,602.00	78.60	3.68	15.60
2010	64,083.00	78.80	4.06	14.80
2011	65,628.00	80.00		
2012	63,562.00	79.90		
2013	66,505.00	79.90		

Source: Kyoto Prefecture, 2015

Table 3.8 Total Tea Production Weight (Kg) and Harvested Tea Plantation Area (Ha)

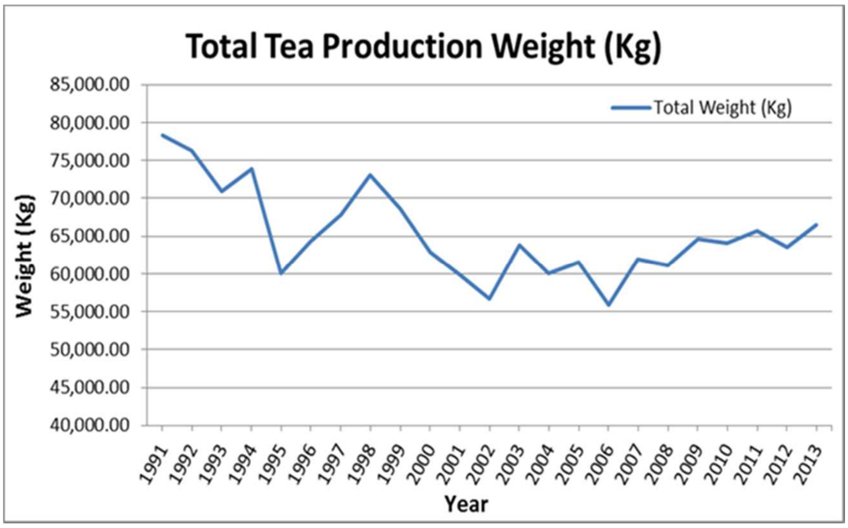


Figure 3.21 Total Uji Area Tea Production Weight (Kg) 1991 to 2013

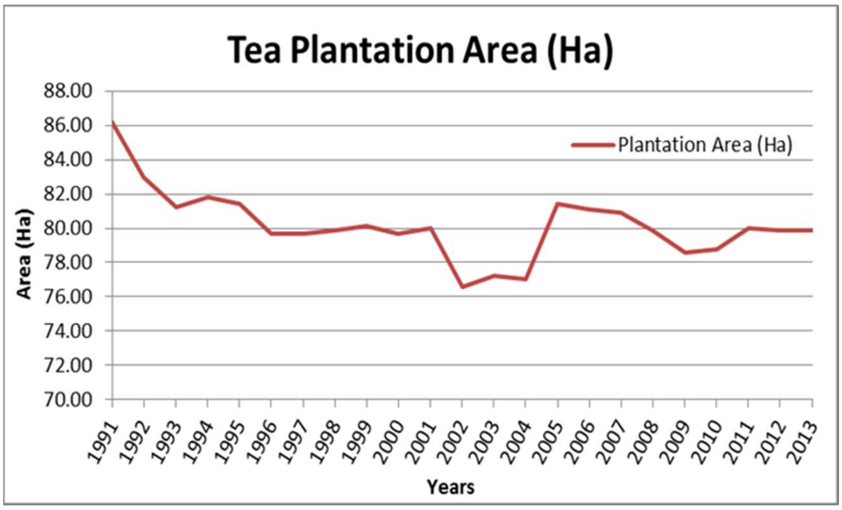


Figure 3.22 Harvested Tea Plantation Area in Uji Area (Ha) 1991 to 2013

Year	Tea Productivity (Kg/Ha)	Tencha (Kg)	Gyokuro (Kg)
1991	909.05	56,580.00	13,281.00
1992	918.57	53,725.00	12,338.00
1993	873.30	51,040.00	11,104.00
1994	902.96	51,746.00	12,216.00
1995	737.73	41,749.00	10,603.00
1996	807.14	44,335.00	11,631.00
1997	850.43	49,806.00	9,615.00
1998	915.36	53,189.00	11,396.00
1999	856.98	49,200.00	11,560.00
2000	789.17	44,957.00	10,563.00
2001	748.79	44,394.00	8,890.00
2002	740.16	41,428.00	8,890.00
2003	826.00	45,258.00	10,748.00
2004	779.88	42,614.00	10,183.00
2005	755.25	43,466.00	10,488.00
2006	688.42	39,476.00	9,348.00
2007	765.19	44,139.00	10,224.00
2008	764.97	43,443.00	10,171.00
2009	821.91	41,670.00	13,648.00
2010	813.24	41,175.00	13,735.00
2011	820.35	42,604.00	13,833.00
2012	795.52	42,503.00	13,809.00
2013	832.35	45,274.00	13,985.00

Source: Kyoto Prefecture, 2015

Table 3.9 Tea Productivity (Kg/Ha), Tencha Weight (Kg) and Gyokuro Weight (Kg)

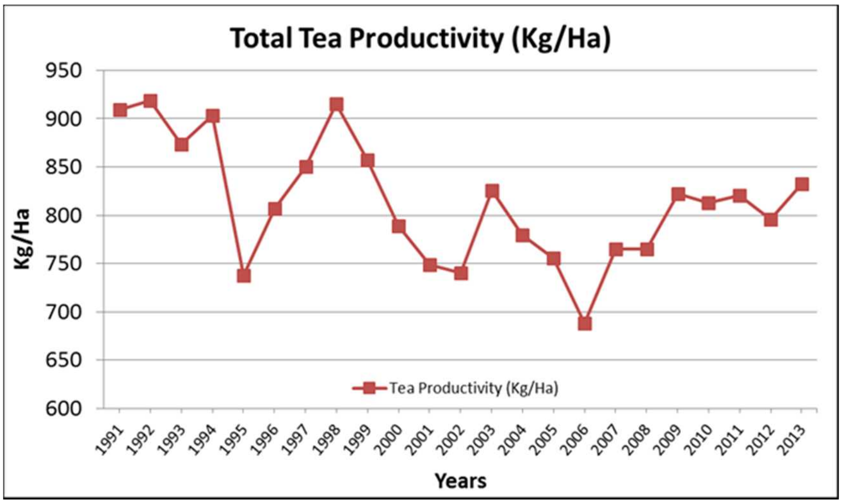


Figure 3.23 Tea Productivity (Kg/Ha) in Uji Area (1991 to 2013)

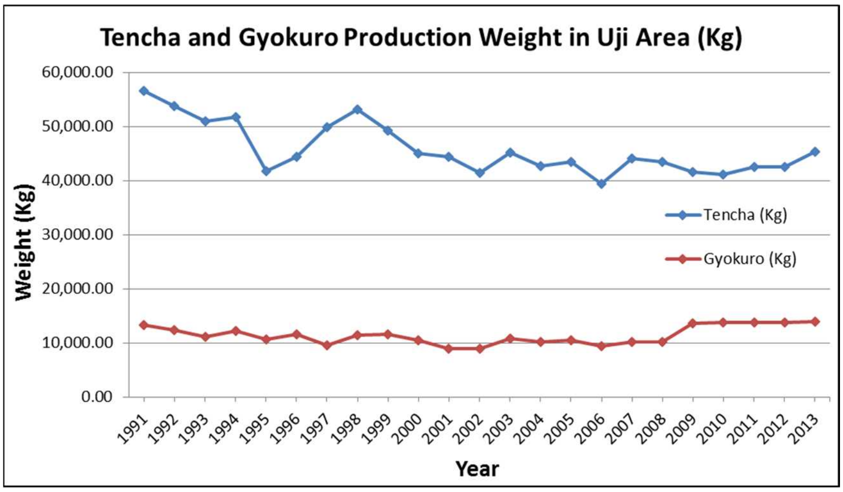


Figure 3.24 Tencha and Gyokuro Production Weight (Kg) in Uji Area (1991 to 2013)

From figure 3.21 it can be observed that consistent with the drop in tea production weight, the tea productivity also significantly dropped in the year 2002 and 2006, which is caused by changing micro-climatic conditions. Further details of the tea production as shown in figure 3.24 indicates that the two most produced tea types in Uji Area are *tencha* and *gyokuro*. Their combined production weight accounts for around 90 percent of the total tea production in Uji Area.

From the figure it can be seen that there were declines on *tencha* production, as reflected by the total yield, caused by climatic changes (table 3.8), while interestingly *gyokuro* production is stable with the tendency to increase. The increase of *gyokuro* production could be attributed to the new cultivation process adaptations which have carried out by the tea growers from 2009, where early harvest would also advance *gyokuro* production in comparison with other tea products because tea leaf harvesting activity to be conducted in first flush harvesting.

3.3 Chapter Summary

In relation with Research Question 1: "How do changes in the climate factors of the terroir elements impact the other terroir elements of Uji Area tea cultivation?" the findings are:

- Changes in the climatic factors have affected other elements in the Natural Environmental Elements where the following tendencies/trends were identified:
    - Fluctuations in average mean air temperature, especially fluctuations towards higher temperature on late February (2c) and mid March (3b). There is also tendency for the seasonal average mean air temperature value to increase (table 3.1; figure 3.2; figure 3.3).
    - Fluctuations in average minimum air temperature, especially fluctuations towards higher temperature on late February (2c). Increasing trend of seasonal average minimum air temperature value is also evident (table 3.2; figure 3.4; figure 3.5).
    - Fluctuations in average maximum air temperature, especially fluctuations towards higher temperature in mid February (2b) and late February (2c), and temperature drop in mid March (3b). It was also apparent that the seasonal average maximum air temperature value is increasing (table 3.3; figure 3.6; figure 3.7).
    - Changing precipitation volume especially noteworthy being the increase in the period of early April (4a) and late April (4c). Increasing trend of seasonal precipitation volume is also evident (table 3.4; figure 3.8; figure 3.9).
    - Increasing trend of humidity level is evident (table 3.5; figure 3.10; figure 3.11).

- Changes in the climatic factors have also affected other terroir elements of the Agriculture Practices Elements where there were identifiable changes in the tea cultivation process. These changes are listed below:
    - Tea harvesting is conducted earlier than before.
    - Deep soil treatment is conducted at later period than usual.
    - Leaf covering is conducted even before the beginning of the season.
    - Light leaf covering is used in the summer
    - Watering is conducted in the tea plantation.
    - Installation of frost fan system in tea plantation especially in the hill side.

- Changes in the climatic condition have overwhelmed other elements in the terroir concept and have been directly affecting both the natural environmental elements and agriculture practices elements.

CHAPTER 4

BIO-CLIMATIC INDICATORS

4.1 Terroir and Bio-Climatic Indicators

Developed from the winegrape cultivation analysis, bio climatic indicators are established as a function of a mean vegetative cycle of the grape. These indices are important to characterize the climatic potentials of a region (environmental elements of terroir concept), and are strongly linked to the qualitative potential and to the characteristics of the grapes or viticultural products. For this underlying reason, this research is an attempt to implement the terroir concept in order to develop and utilize these bio climatic indices for tea cultivation in Uji Area.

Because of the differences between the winegrape cultivation process and the tea cultivation process, observations and social surveys were conducted among tea plantations and growers in Uji, from which several key factors characterizing Uji Tea cultivation could be determined. The main identified differences are related to the plant phenology process. Whereas tea cultivation focused on leaf maturation, fruit maturation is critical in winegrape cultivation. Thus the important phenological events started from the appearance of new leaf bud, i.e: new leaf bud break, leaf maturation and ending with leaf harvesting. Based on these phenological process differences, the period for first flush harvest tea cultivation, i.e: from bud break to leaf harvest, is shorter than the time between bud break and fruit harvest for winegrape cultivation.

Winegrape cultivation takes place over 6 months from leaf bud break, fruit maturation, and ending with harvest, whereas in the tea cultivation, from leaf bud break to leaf maturation and leaf harvest, only lasted for 1 month. In view of these differences, the bio-climatic indicators which are utilized in winegrape cultivation could not be immediately applied in the tea cultivation without reformulation and recalculation based on an analysis of what is best suited to the particularities of the tea cultivation process.

Based on surveys and observations data discussed in the previous chapter, it was evident that the Uji tea growers have regarded the natural environmental elements as very crucial in the Uji tea cultivation process. The identified factors from cross referencing analysis (figure 3.10), clearly showed how air temperature factors as well as soil management factors are highly considered by Uji tea growers as the most crucial factors in the tea cultivation process. Whereas the information on types and timing of cultivation interventions in adjusting the air temperature and climatic factors impacts are openly shared, information regarding soil management are closely guarded by the tea growers as a trade secret.

Through analysis of the air temperature and the climatic factors, similar key bio-climatic indicators derived from winegrape cultivation analysis could be utilized in tea cultivation, where the values would correspond with the crucial factors of Uji Area climatic condition. The applicable bio-climatic indicators developed from the key factors shown in figure 4.1 are: 1) Heliothermal Index; 2) Cool Night Index; and 3) Humidity (as a proxy for Dryness Index), and the additional indicator developed from the Cool Night Index is: 4) Warm Day Index.

On the winegrape cultivation, these bio-climatic indicators represent important information on the natural environment elements especially on climatic factors, which provide detailed analysis for the winegrape growers for selecting suitable cultivars and land plot in winegrape cultivation as well as for conducting cultivation interventions.

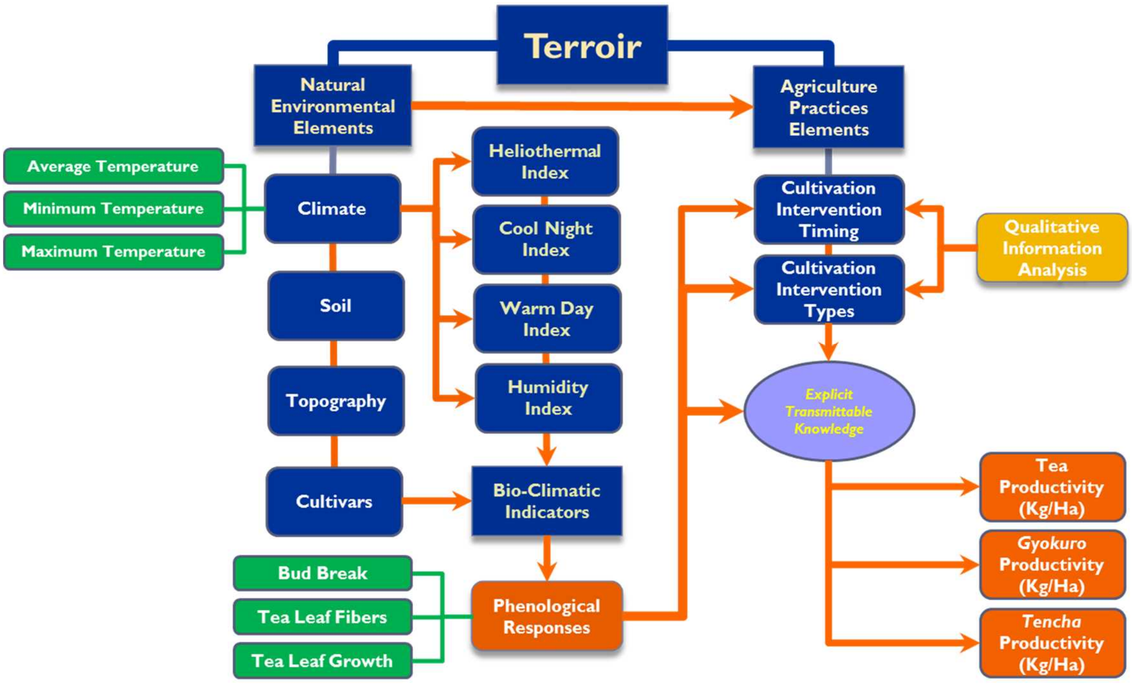


Figure 4.1 Application of Bio-Climatic Indicators in Uji Tea Cultivation

4.2 Heliothermal Index

Originally Heliothermal Index (HI) is a viticultural climate index developed by Huglin which estimates the heliothermal potential of a specific climatic condition; temperature calculations consider the period of the day in which grapevine metabolism is more active; the index also includes a correction factor for the length of the day in higher latitudes. In the case of tea cultivation HI values indicate the condition for tea plants growth (above 10^{o}C) typically on late winter and early spring.

For tea cultivation HI can be utilized to identify suitable locations for tea growing, as temperature factor has a significant impact on the tea cultivation. This approach is important to identify suitable tea growing locations, whereas HI values combined with other factors such as soil and topography factors could be utilized to interpret the micro-climate condition of a certain land area for tea cultivation. HI values could also be utilized for prediction of optimal cultivation intervention timing.

$$HI = \sum_{day\ n}^{day\ 1} \frac{[(T - 10) + (Tx - 10)]}{2} d$$

Whereas:

T = Mean Air Temperature

Tx = Maximum Air Temperature

d = Length of day coefficient ranging from 1 for lower than 40° latitude and 1.02 to 1.06 for 40° to 50° latitude

Based on winegrape growth cycle in the northern hemisphere, HI value is calculated based on cumulative thermal value on the period of April (bud break) to September (harvest). As previously mentioned, the first flush tea cultivation growth cycle happened in a shorter time period, only approximately a month between late March – early April (leaf bud break) to May (harvest). Despite its short growth cycle period, it was evident that the tea growers in Uji Area have started to conduct cultivation intervention as early as late January to early February by applying fertilizer on their tea plantation.

In general tea plants will only be in full metabolism when the air temperature is above 10°C, which usually occurs by the end of February. Thus based on their knowledge, the tea growers conducted cultivation interventions around late January to early February, which indicates that tea plants may have slowly restarted their metabolism as early as January. The new leaf bud will start appearing around mid March and followed by bud break in late March to early April and, upon leaf maturation which occurred around late April to early May the tea leaves could be harvested as fist flush tea harvest.

Based on these observations, HI calculation for tea cultivation in Uji Area is conducted over the period of February to May. Calculation of HI values is conducted using similar methods as for winegrape cultivation which is a cumulative thermal value throughout the cultivation period whereas in this case is from early February to early May. In order to conform with the previous analyses conducted in chapter 3, the climatic data would be averaged into three periods on each month before cumulative value could be calculated. The HI values are calculated based on 10 data sets from early February (2a) to early May (5a) which are derived from the average mean air temperature data (table 4.1), whereas the values used have been reformulated for tea cultivation as indicated earlier. For each 10 day period, the result indicated in Table 4.1 are based on the following HI equation:

$$HI = \left(\sum_{day\ 10}^{day\ 1} \frac{[(T-10)+(Tx-10)]}{2} d \right) + \left(\sum_{day\ 20}^{day\ 11} \frac{[(T-10)+(Tx-10)]}{2} d \right) + \left(\sum_{day\ 30}^{day\ 21} \frac{[(T-10)+(Tx-10)]}{2} d \right) + \cdots$$

	2002	2003	2004	2005	2006	2007	2008	2009	2010
2a	-3.80	-2.30	-3.30	-3.55	-4.45	-1.10	-4.75	-1.75	-2.30
2b	-3.70	-4.05	-0.20	-2.60	-1.85	-0.90	-3.90	-0.10	-2.90
2c	-1.40	1.00	1.50	-3.50	-0.60	0.75	-2.75	-0.30	4.35
3a	-2.50	-0.25	-1.85	-0.40	-0.40	1.65	-0.85	0.55	0.60
3b	0.20	4.50	3.30	-0.45	-1.30	-2.60	4.85	3.30	3.50
3c	3.25	3.45	3.35	1.45	0.95	3.95	4.05	2.00	0.10
4a	6.35	7.80	5.80	6.95	3.50	3.60	5.40	5.50	6.15
4b	8.30	8.00	11.25	7.60	5.35	6.85	7.30	11.50	5.35
4c	6.45	9.65	9.20	11.35	6.30	9.65	10.55	7.45	6.00
5a	10.50	11.15	12.00	11.45	12.00	11.75	12.75	11.40	12.80
HI	23.65	38.95	41.05	28.30	19.50	33.60	32.65	39.55	33.65

Table 4.1 Heliothermal Index Values from Early February (2a) to Early May (5a) (2002-2010)

Based on the approach utilized in winegrapes cultivation for categorizing HI values, similar categorization could be constructed using the HI values calculated from the tea cultivation in Uji Area, which are:

$HI \leq 10$ → Very Cool

$10 < HI \leq 20$ → Cool

$20 < HI \leq 30$ → Temperate

$30 < HI \leq 40$ → Temperate Warm

$40 < HI \leq 50$ → Warm

$50 < HI$ → Very Warm

As seen in table 4.1 the HI values varied broadly ranging from 19.50 to 41.05 in the period of 9 years. This values are related with the environmental conditions especially micro-climatic conditions in the tea plantation. From the correlation between HI values with Uji Area tea production data it can be observed that HI values in the category of Temperate Warm would be beneficial to the first flush tea productivity (Kg/Ha).

In order to further understand the relation between HI values with tea production data, regression analysis was conducted to see the relationship between HI values and tea productivity data from 2002 to 2010. The analysis was conducted with HI values as the independent variable and tea productivity (Kg/Ha) as the dependent variable (table 4.2; figure 4.2). Results of the regression analysis showed that HI values affect the first flush tea productivity (Kg/Ha) in Uji Area with the regression model: *Tea Productivity (Kg/Ha) = 604.569 + (5.204 x HI Value)*, whereas the difference between real values and predicted values is shown in table 4.3.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.867[a]	.752	.717	23.45123

a. Predictors: (Constant), HI

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	11690.404	1	11690.404	21.257	.002[a]
	Residual	3849.722	7	549.960		
	Total	15540.126	8			

a. Predictors: (Constant), HI
b. Dependent Variable: Tea_Productivity_KgHa

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	604.569	37.312		16.203	.000	516.339	692.798
	HI	5.204	1.129	.867	4.611	.002	2.535	7.873

a. Dependent Variable: Tea_Productivity_KgHa

Table 4.2 Regression Result for HI Values on Tea Productivity (Kg/Ha) (2002-2010)

Year	HI Values	Tea Productivity (Kg/Ha)	Predicted Tea Productivity (Kg/Ha)	Difference
2002	23.65	740.16	727.64	-12.51
2003	38.95	826.00	807.26	-18.73
2004	41.05	779.88	818.19	38.31
2005	28.30	755.25	751.84	-3.40
2006	19.50	688.42	706.05	17.63
2007	33.60	765.19	779.42	14.23
2008	32.65	764.97	774.48	9.51
2009	39.55	821.91	810.39	-11.52
2010	33.65	813.24	779.68	-33.55

Table 4.3 HI Values on Tea Productivity (Kg/Ha)

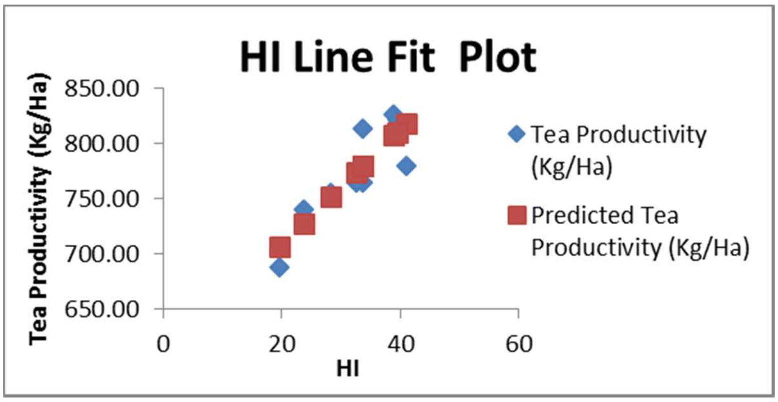


Figure 4.2 HI Values Line Fit Plot on Tea Productivity (Kg/Ha)

Further analysis conducted on HI values with the tea productivity have revealed, combination of HI value with the mean precipitation value from early January (1a) to early May (5a) (table 4.4) further increase the fit of the regression, even though regression analysis between precipitation and tea productivity did not produce any significance (table 4.5).

Year	2002	2003	2004	2005	2006	2007	2008	2009	2010
Mean Precipitation	29.67	42.09	30.12	24.28	36.72	20.81	33.52	39.15	49.57

Table 4.4 Mean Precipitation (mm) From Early January (1a) to Early May (5a) (2002-2010)

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.465[a]	.216	.104	41.70805

a. Predictors: (Constant), Precipitation

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3363.199	1	3363.199	1.933	.207[a]
	Residual	12176.927	7	1739.561		
	Total	15540.126	8			

a. Predictors: (Constant), Precipitation
b. Dependent Variable: Tea_Productivity_KgHa

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	695.116	57.559		12.077	.000	559.011	831.222
	Precipitation	2.285	1.643	.465	1.390	.207	-1.601	6.170

a. Dependent Variable: Tea_Productivity_KgHa

Table 4.5 Regression Result for Precipitation on Tea Productivity (Kg/Ha) (2002-2010)

Thereby it could be concluded from the analysis, the combination of HI value and Precipitation would further affect the first flush tea productivity level (Kg/Ha), where the regression model (shown in table 4.6; figure 4.3; figure 4.4) is as follows: *Tea Productivity (Kg/Ha) = 564.698 + (4.845 x HI Value) + (1.515 x Precipitation)* whereas the difference between real values and predicted values is shown in table 4.7.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.919[a]	.844	.792	20.11377

a. Predictors: (Constant), Precipitation, HI

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	13112.744	2	6556.372	16.206	.004[a]
	Residual	2427.382	6	404.564		
	Total	15540.126	8			

a. Predictors: (Constant), Precipitation, HI
b. Dependent Variable: Tea_Productivity_KgHa

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	564.698	38.423		14.697	.000	470.681	658.715
	HI	4.845	.987	.807	4.909	.003	2.430	7.260
	Precipitation	1.515	.808	.308	1.875	.110	-.462	3.491

a. Dependent Variable: Tea_Productivity_KgHa

Table 4.6 Regression Result for HI Values and Precipitation on Tea Productivity (Kg/Ha) (2002-2010)

Year	HI Values	Mean Precipitation (mm)	Tea Productivity (Kg/Ha)	Predicted Tea Productivity (Kg/Ha)	Difference
2002	23.65	29.67	740.16	724.23	-15.93
2003	38.95	42.09	826.00	817.18	-8.82
2004	41.05	30.12	779.88	809.22	29.34
2005	28.30	24.28	755.25	738.60	-16.64
2006	19.50	36.72	688.42	714.81	26.39
2007	33.60	20.81	765.19	759.01	-6.18
2008	32.65	33.52	764.97	773.67	8.71
2009	39.55	39.15	821.91	815.62	-6.28
2010	33.65	49.57	813.24	802.83	-10.41

Table 4.7 HI Values and Precipitation on Tea Productivity (Kg/Ha)

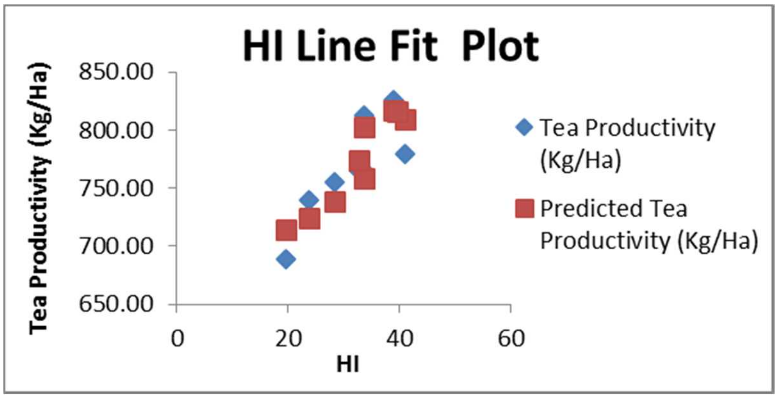


Figure 4.3 HI Values Line Fit Plot on Tea Productivity (Kg/Ha)

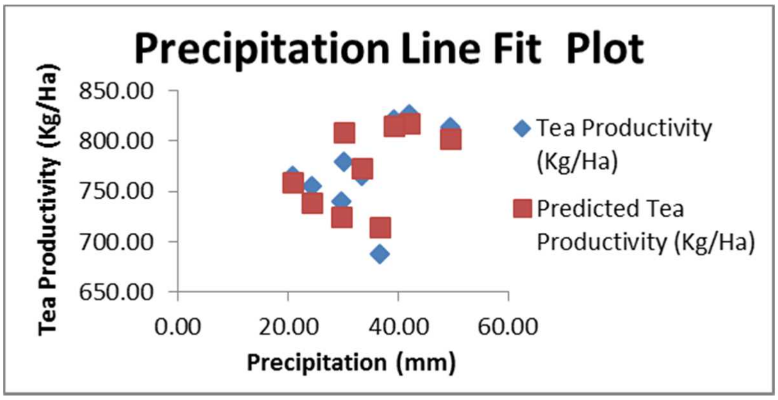


Figure 4.4 Precipitation Line Fit Plot on Tea Productivity (Kg/Ha)

From the climatic data measurement and monitoring conducted in two tea plantations in 2014, the HI values were calculated using the formula derived from the regression [Tea Productivity (Kg/Ha) = 564.698 + (4.845 x HI Value) + (1.515 x Precipitation)] to predict the tea productivity level on both sites.

	Koyama-en	Shichimei-en
2a	-3.03	-4.29
2b	-4.66	-3.74
2c	-0.70	1.28
3a	-2.34	-2.90
3b	1.65	2.60
3c	4.31	4.30
4a	5.84	5.63
4b	7.16	7.01
4c	9.84	9.57
5a	11.49	11.46
HI	29.56	30.92

Table 4.8 HI Values on Koyama-en and Shichimei-en (2014)

	Koyama-en	Shichimei-en
1a	33.38	30.69
1b	3.00	1.75
1c	19.12	15.56
2a	21.54	10.40
2b	28.00	23.00
2c	8.53	0.00
3a	18.00	18.40
3b	42.70	42.00
3c	68.80	62.60
4a	12.78	10.80
4b	8.82	7.20
4c	30.88	33.20
5a	0.25	1.40
Mean Precipitation	22.75	19.77

Table 4.9 Mean Precipitation on Koyama-en and Shichimei-en (2014)

Therefore the predicted tea productivity for Koyama-en is 724.41 Kg/Ha, while for Shichimei-en is 744.45 Kg/Ha

4.3 Cool Night Index

Cool Night Index (CI) is originally a viticultural climate index developed to estimate the minimum temperature condition that affects the phenology of a plant. This index serves as an indication of winegrape region's potential characteristics with respect to secondary metabolites (polyphenols, aromas, color) in grapes and wines. For tea cultivation, CI values could be utilized to evaluate the growth of first flush tea leaf. This is also true for most of the high quality teas from other regions, which are usually grown in the highlands in order to obtain a cool climatic condition to capture subtleties in the aroma, flavor, leaf fiber (soft leaves are desirable), etc. which reflect the quality of a product. In such climatic conditions, the slow growth of the tea plants enhances this attributes.

In the winegrape cultivation, CI value is calculated based on average minimum air temperature in September during the ripening period prior to harvest. As mentioned previously because the tea growth cycle only lasted a month from leaf bud break to harvest, which is the period of tea leaf maturation, reformulation of the calculation period is necessary.

$$CI = mean\ (T_{min})\ for\ important\ cultivation\ process\ period\ in\ ^{o}C$$

With respect to the tea growth cycle, tea plants will enter a period of inactivity when the air temperature drops below 10°C. Therefore tea plants are in a dormant state generally until February. Although in a dormant state, based on observations of the timing of cultivation interventions, which embody traditional agricultural knowledge in this long-standing tea growing region, the tea plants may have slowly restarted its metabolism as early as January depending on its micro-climatic conditions, whereas in general the tea plants are seen to be in active metabolism around late February. Tea harvesting is conducted within a month period after bud break, and it appears that each tea grower has their own timing based on the environmental conditions of their tea plantation, therefore the micro-climatic conditions on April seem to be crucial to decide harvest timing.

As in the case of HI calculation earlier, the climatic data is averaged into three periods for each month before the total average value could be calculated. Based on these observations, CI for tea cultivation in Uji Area is calculated on the average minimum air temperature over the period of January (start of tea plants metabolism) to April (end of leaf maturation period). These CI values can be seen in table 4.10 and are calculated as indicated below:

$$CI = mean\ (mean\ (T_{min})(d1\text{-}d10) + mean\ (T_{min})(d11\text{-}d20) + mean\ (T_{min})(d21\text{-}d30))$$

for important cultivation process period in ºC

	2002	2003	2004	2005	2006	2007	2008	2009	2010
1a	0.00	-1.00	0.40	-0.40	-1.50	0.90	0.50	1.40	0.50
1b	-2.90	2.30	0.70	0.60	0.70	-0.30	0.30	-0.80	-1.10
1c	-0.30	0.20	-1.80	-0.40	-0.90	-0.40	0.70	1.10	0.40
2a	-0.40	-0.50	-1.00	0.70	-0.60	0.10	-0.60	-0.40	0.80
2b	-1.80	-1.20	-0.80	1.30	0.90	0.60	-0.80	1.50	0.40
2c	-0.30	2.60	2.30	-1.40	1.50	0.80	-0.90	3.30	6.50
3a	0.20	0.70	0.00	0.70	1.70	1.50	0.40	3.10	5.70
3b	0.10	3.10	2.10	1.10	1.00	-0.50	5.40	2.80	3.30
3c	4.30	3.30	4.60	2.90	1.90	3.20	4.40	2.30	2.90
4a	4.60	7.00	3.80	5.00	4.70	4.30	5.60	3.60	5.80
4b	7.60	7.80	10.60	7.60	8.90	6.60	9.80	10.30	8.80
4c	6.40	11.70	7.60	9.30	7.40	8.80	8.90	7.20	7.70
CI	1.46	3.00	2.38	2.25	2.14	2.13	2.81	2.95	3.48

Table 4.10 Cool Night Index Values from Early January (1a) to Late April (4c) (2002-2010)

Based on the approach utilized in winegrapes cultivation for categorizing CI values, similar categorization could be constructed using the CI values calculated from the tea cultivation in Uji Area, which are:

$CI \leq 1$	→	Very Cool Nights
$1 < CI \leq 2$	→	Cool Nights
$2 < CI \leq 3$	→	Temperate Nights
$3 < CI \leq 4$	→	Warm Nights
$4 < CI$	→	Hot Nights

From the calculation it can be observed that the CI values for 2002 – 2010 are ranging from 1.46 to 3.48; thus from the relation with tea production data from Kyoto Prefecture (2015) showed that CI values in the category of Temperate Nights would be beneficial to the *gyokuro* productivity (Kg/Ha). To further understand the relation between CI values with the *gyokuro* productivity (Kg/Ha), regression analysis is conducted with *gyokuro* producttivity data (Kg/Ha) (2002-2010) shown in table 4.11.

Year	Gyokuro Productivity (Kg/Ha)
2002	116.06
2003	139.22
2004	132.25
2005	128.85
2006	115.27
2007	126.38
2008	127.30
2009	173.64
2010	174.30

Table 4.11 *Gyokuro* Productivity (Kg/Ha) (2002-2010)

Regression analysis is conducted with CI values as independent variable and *gyokuro* productivity (Kg/Ha) as dependent variable (table 4.12; table 4.13; figure 4.5). The regression model is *gyokuro* productivity (Kg/Ha) = 62.302 + (29.759 x CI Value) whereas the result showed that CI values have affected the *gyokuro* productivity (Kg/Ha) in Uji Area.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.811[a]	.658	.610	13.87653

a. Predictors: (Constant), CI

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2597.329	1	2597.329	13.489	.008[a]
	Residual	1347.907	7	192.558		
	Total	3945.236	8			

a. Predictors: (Constant), CI
b. Dependent Variable: Gyokuro_KgHa

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	62.302	20.866		2.986	.020	12.962	111.643
	CI	29.759	8.103	.811	3.673	.008	10.599	48.919

a. Dependent Variable: Gyokuro_KgHa

Table 4.12 Regression Result for CI Values on *Gyokuro* Productivity (Kg/Ha) (2002-2010)

Year	CI Values	*Gyokuro* Productivity (Kg/Ha)	Predicted *Gyokuro* Productivity (Kg/Ha)	Difference
2002	2.30	116.06	130.75	14.69
2003	3.83	139.22	176.38	37.16
2004	3.24	132.25	158.85	26.61
2005	3.02	128.85	152.24	23.40
2006	3.04	115.27	152.90	37.64
2007	2.82	126.38	146.29	19.91
2008	3.58	127.30	168.77	41.48
2009	3.74	173.64	173.73	0.09
2010	4.66	174.30	200.85	26.54

Table 4.13 CI Values on *Gyokuro* Productivity (Kg/Ha)

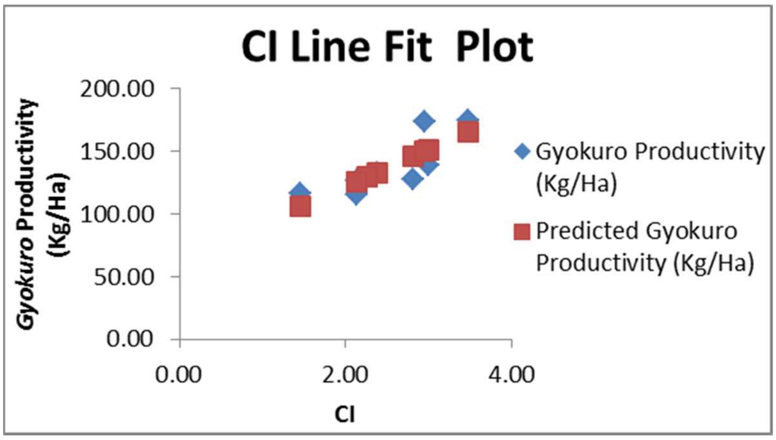


Figure 4.5 CI Values Line Fit Plot on *Gyokuro* Productivity (Kg/Ha)

As shown in table 4.14 further regression analysis between CI values with the tea productivity also showed that CI values have also affected the tea productivity values, although the degree is not high.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.733[a]	.538	.472	32.02798

a. Predictors: (Constant), CI

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	8359.585	1	8359.585	8.149	.025[a]
	Residual	7180.541	7	1025.792		
	Total	15540.126	8			

a. Predictors: (Constant), CI
b. Dependent Variable: Tea_Weight_KgHa

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	638.717	48.160		13.262	.000	524.835	752.598
	CI	53.388	18.702	.733	2.855	.025	9.166	97.611

a. Dependent Variable: Tea_Weight_KgHa

Table 4.14 Regression Result for CI Values on Tea Productivity (Kg/Ha) (2002-2010)

Based on the calculated CI values from the other climatic data measurement and monitoring locations (table 4.15), the predicted *gyokuro* productivity could be calculated using the formula, *gyokuro* productivity (Kg/Ha) = 62.302 + (29.759 x CI Value).

	Koyama-en	Shichimei-en
1a	0.47	-0.32
1b	-1.47	-2.34
1c	0.10	-0.75
2a	1.22	1.63
2b	-0.25	-0.52
2c	1.60	2.04
3a	1.22	-0.11
3b	2.92	4.26
3c	5.86	6.11
4a	5.07	5.47
4b	5.96	6.41
4c	10.11	10.26
CI	2.73	2.68

Table 4.15 CI Values on Koyama-en and Shichimei-en (2014)

Therefore the predicted *gyokuro* productivity for Koyama-en is 143.68 Kg/Ha, while for Shichimei-en is 142.02 Kg/Ha

4.4 Humidity Index

In this research humidity values are used as a proxy of Dryness Index which derived from winegrape cultivation. Dryness value indicates the potential water availability in the soil, related to the level of dryness in a region which is important in regard to grape ripening level and wine quality. In order to produce high quality wine, winegrape is ideally grown at a certain level of climatic dryness so that upon maturation the fruits would contain less water, which is a desirable traits in the matured fruits for making quality wines.

In the case of tea cultivation, moderately high humidity is important for the growth of the new tea leaves as opposed to the winegrape. Therefore as a proxy for the Dryness Index, average mean humidity values were used to indicate the tea production level. Humidity value weres averaged into three periods on each month before Humidity Index value could be calculated.

$$\text{Hum-I} = \text{mean}\,(\text{mean RH}\,(d1\text{-}d10) + \text{mean RH}\,(d11\text{-}d20) + \text{mean RH}\,(d21\text{-}d30))$$

for important cultivation process period in %

Humidity Index values are calculated for the same period as Heliothermal Index, viz: from early February (2a) to early May (5a), because in this period the tea plants presumably are beginning to have active metabolism from early February (2a) and harvesting is conducted from early May (5a) as shown in table 4.16.

Year	2002	2003	2004	2005	2006	2007	2008	2009	2010
2a	76.40	76.10	72.30	70.90	73.80	71.70	82.10	76.40	79.10
2b	67.70	72.10	76.40	75.90	75.80	73.20	75.10	77.40	79.60
2c	72.60	72.00	79.60	69.30	76.00	71.30	74.40	79.90	82.00
3a	69.10	69.40	75.20	71.30	76.90	68.70	75.40	75.70	88.20
3b	67.30	65.10	74.70	73.90	74.10	68.30	73.70	74.90	75.00
3c	67.90	71.30	78.10	72.10	70.50	75.30	73.20	69.10	77.80
4a	66.00	66.00	73.30	65.80	69.60	70.10	72.40	69.20	71.80
4b	63.00	71.10	74.50	67.00	73.60	67.40	78.20	67.70	78.20
4c	67.10	72.00	69.80	61.70	68.10	70.60	71.20	70.10	71.30
5a	76.00	77.10	78.80	69.80	73.80	75.30	70.10	67.50	69.90
Hum-I	69.31	71.22	75.27	69.77	73.22	71.19	74.58	72.79	77.29

Table 4.16 Humidity Index Values from Early February (2a) to Early May (5a) (2002-2010)

Although regression analysis between Hum-I and tea productivity resulted in negative relation (table 4.17), further analysis on the tea productivity have showed, with the addition of Hum-I values to other bio-climatic indicators as indicated below, tea productivity (Kg/Ha) could be better predicted by this composite index. Regression analysis was conducted with multiple independent variables, viz: HI values, Mean Precipitation, CI values and Hum-I values. The result showed showed that the combination values from the four indices significantly affects tea productivity (Kg/Ha).

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.262[a]	.069	-.064	45.47099

a. Predictors: (Constant), Hum_I

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1066.852	1	1066.852	.516	.496[a]
	Residual	14473.274	7	2067.611		
	Total	15540.126	8			

a. Predictors: (Constant), Hum_I
b. Dependent Variable: Tea_Productivity_KgHa

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	455.357	442.157		1.030	.337	-590.177	1500.891
	Hum_I	4.364	6.075	.262	.718	.496	-10.002	18.730

a. Dependent Variable: Tea_Productivity_KgHa

Table 4.17 Regression Result for Hum-I Values on Tea Productivity (Kg/Ha) (2002-2010)

As shown in table 4.18; table 4.19; figure 4.6; figure 4.7; figure 4.8; and figure 4.9; the regression model is Tea Productivity (Kg/Ha) = 998.187 + (4.503 x HI Value) + (1.550 x Mean Precipitation) + (23.362 x CI Value) - (6.630 x Hum-I Value).

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.964[a]	.929	.857	16.64106

a. Predictors: (Constant), Hum_I, HI, Precipitation, CI

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	14432.427	4	3608.107	13.029	.015[a]
	Residual	1107.699	4	276.925		
	Total	15540.126	8			

a. Predictors: (Constant), Hum_I, HI, Precipitation, CI
b. Dependent Variable: Tea_Productivity_KgHa

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	998.187	202.960		4.918	.008	434.681	1561.694
	HI	4.503	1.132	.750	3.976	.016	1.359	7.647
	Precipitation	1.550	1.148	.316	1.350	.248	-1.638	4.737
	CI	23.362	21.828	.321	1.070	.345	-37.243	83.967
	Hum_I	-6.630	3.078	-.398	-2.154	.098	-15.176	1.915

a. Dependent Variable: Tea_Productivity_KgHa

Table 4.18 Regression Result for HI Values, Mean Precipitation, CI Values and Hum-I Values on Tea Productivity (Kg/Ha) (2002-2010)

Year	HI Values	Mean Precipitation	CI Values	Hum-I Values	Tea Productivity (Kg/Ha)	Predicted Tea Productivity (Kg/Ha)	Difference
2002	23.65	29.67	2.30	69.31	740.16	744.88	4.72
2003	38.95	42.09	3.83	71.22	826.00	856.19	30.19
2004	41.05	30.12	3.24	75.27	779.88	806.48	26.60
2005	28.30	24.28	3.02	69.77	755.25	771.29	16.05
2006	19.50	36.72	3.04	73.22	688.42	728.59	40.17
2007	33.60	20.81	2.82	71.19	765.19	775.68	10.49
2008	32.65	33.52	3.58	74.58	764.97	786.29	21.32
2009	39.55	39.15	3.74	72.79	821.91	841.84	19.93
2010	33.65	49.57	4.66	77.29	813.24	822.88	9.64

Table 4.19 HI Values, Mean Precipitation, CI Values and Hum-I Values on Tea Productivity (Kg/Ha) (2002-2010)

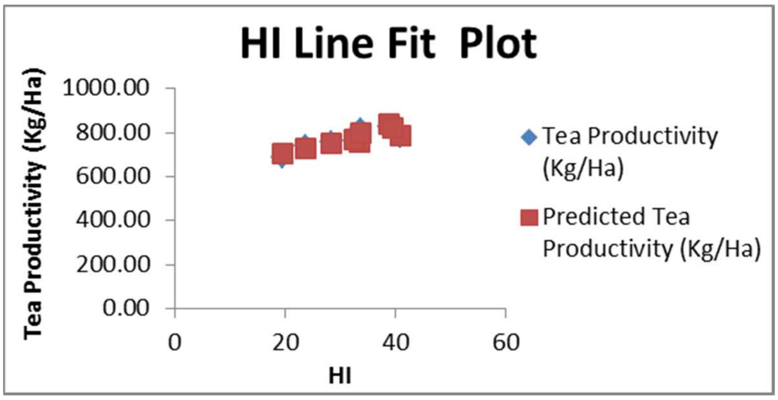


Figure 4.6 HI Values Line Fit Plot on Tea Productivity (Kg/Ha)

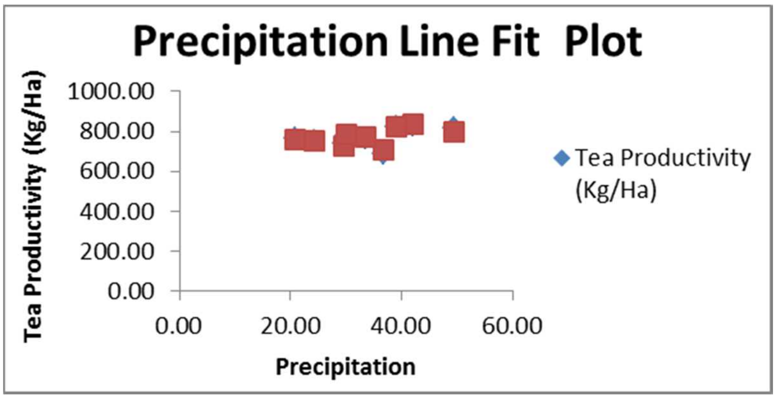


Figure 4.7 Precipitation Values Line Fit Plot on Tea Productivity (Kg/Ha)

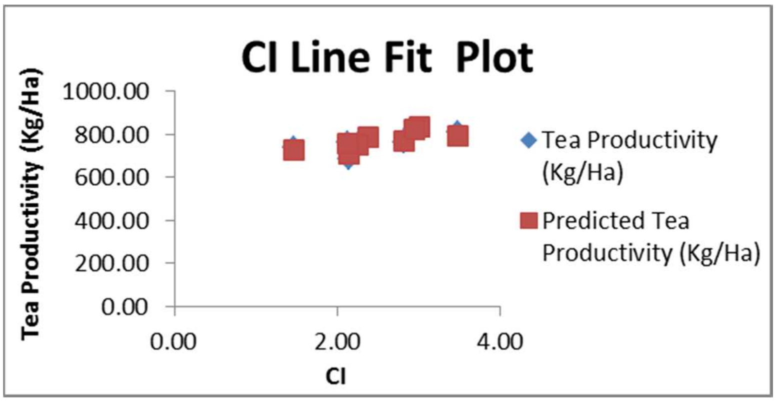


Figure 4.8 CI Values Line Fit Plot on Tea Productivity (Kg/Ha)

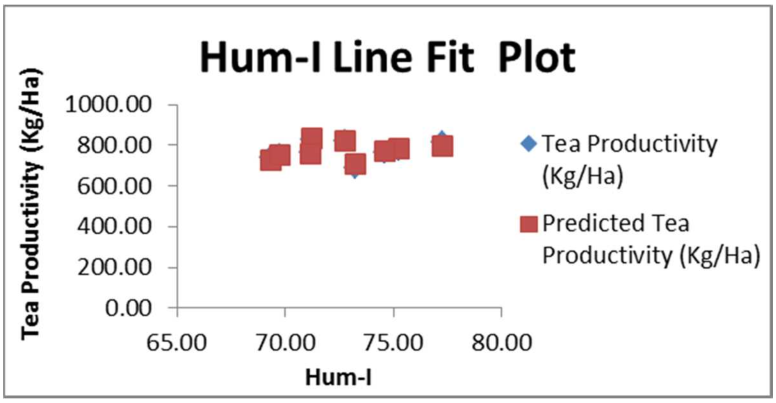


Figure 4.9 Hum-I Values Line Fit Plot on Tea Productivity (Kg/Ha)

From the two monitoring locations, using a composite index compromising of HI values (table 4.18), mean precipitation (table 4.9), CI values (table 4.15), and Hum-I (table 4.20) the tea productivity could be predicted using the formula, tea productivity (Kg/Ha) = 998.187 + (4.503 x HI Value) + (1.550 x Mean Precipitation) + (23.362 x CI Value) - (6.630 x Hum-I Value). The tea productivity prediction for Koyama-en is 767.36 Kg/Ha, while for Shichimei-en it is 778.57 Kg/Ha

	Koyama-en	Shichimei-en
2a	78.75	77.49
2b	73.25	70.38
2c	72.11	73.11
3a	74.37	78.41
3b	73.20	67.32
3c	71.56	69.03
4a	67.42	63.97
4b	57.02	54.61
4c	68.32	66.88
5a	62.46	60.65
Hum-I	69.85	68.19

Table 4.20 Hum-I Values on Koyama-en and Shichimei-en (2014)

4.5 Warm Day Index

As a way to further understand the micro-climatic conditions during the tea cultivation process, particularly in the leaf growth period, the Warm Day Index (WI) is useful. It complements Cool Night Index (CI) values, which may be seen as opposite to WI values which evaluate the maximum day time temperature when tea leaves are growing. WI is derived from CI conceptually, where instead evaluating the minimum night temperature, this indicator evaluates the opposite, viz: the maximum day temperature of the period where important phenological and cultivation events occur. Based on CI, WI values are calculated as follows:

$$WI = mean\ (mean\ (T_{max})(d1\text{-}d10) + mean\ (T_{max})(d11\text{-}d20) + mean\ (T_{max})(d21\text{-}d30))$$

for important cultivation process period in ºC

While CI values evaluates the cool climatic condition during first flush tea leaf growth, WI values would analyze heat effect towards tea plants growth as warm temperature will increase the plants metabolism. Based on social survey and observations, the first flush leaf buds will start to appear by the early March (3a) and will be in mature condition on late April (4c). From this analysis WI value is calculated based on the average maximum temperature over the period of early March (3a) to late April (4c) which shown in table 4.21.

	2002	2003	2004	2005	2006	2007	2008	2009	2010
3a	9.90	12.80	11.00	13.00	12.50	15.30	12.40	13.20	12.40
3b	13.60	18.30	17.20	12.40	11.20	10.20	18.20	16.90	17.10
3c	16.20	16.90	16.40	14.20	14.40	17.60	17.40	15.70	12.80
4a	20.30	21.40	19.70	20.90	16.40	16.80	18.80	20.00	19.70
4b	21.90	21.40	25.00	21.10	17.70	20.60	20.10	25.50	17.70
4c	19.80	22.30	23.20	25.40	19.40	23.30	24.70	20.80	18.90
WI	16.95	18.85	18.75	17.83	15.27	17.30	18.60	18.68	16.43

Table 4.21 Warm Day Index Values from Early March (3a) to Late April (4c) (2002-2010)

Based on the approach utilized in categorizing CI values, similar categorization could be constructed using the WI values which are:

$WI \leq 15$ → Very Cool Days

$15 < WI \leq 17$ → Cool Days

$17 < WI \leq 19$ → Temperate Days

$19 < WI \leq 21$ → Warm Days

$21 < WI$ → Hot Days

From the analysis with tea production data from Kyoto Prefecture (2015), the WI values in the category of Temperate Days would be beneficial to the *tencha* productivity (Kg/Ha). To further understand the relation, regression analysis is conducted with WI values as independent variable and *tencha* productivity (Kg/Ha) (table 4.22) as dependent variable.

Year	Tencha Productivity (Kg/Ha)
2002	540.84
2003	586.24
2004	553.43
2005	533.98
2006	486.76
2007	545.60
2008	543.72
2009	530.15
2010	522.53

Table 4.22 *Tencha* Productivity (Kg/Ha) (2002-2010)

Regression result showed that WI values might have significant effect to the total *tencha* productivity (Kg/Ha) in Uji Area (table 4.23; table 4.24; figure 4.10). Result of the regression model is *Tencha productivity (Kg/Ha) = 243.040 + (16.740 x WI Value)*

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.787[a]	.620	.566	17.44206

a. Predictors: (Constant), WI

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3476.615	1	3476.615	11.428	.012[a]
	Residual	2129.579	7	304.226		
	Total	5606.194	8			

a. Predictors: (Constant), WI
b. Dependent Variable: Tencha_KgHa

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	243.040	87.488		2.778	.027	36.163	449.916
	WI	16.740	4.952	.787	3.380	.012	5.030	28.449

a. Dependent Variable: Tencha_KgHa

Table 4.23 Regression Result for WI Values on *Tencha* Productivity (Kg/Ha) (2002-2010)

Year	WI Values	*Tencha* Productivity (Kg/Ha)	Predicted *Tencha* Productivity (Kg/Ha)	Difference
2002	16.95	540.84	526.78	-14.05
2003	18.85	586.24	558.59	-27.65
2004	18.75	553.43	556.92	3.49
2005	17.83	533.98	541.57	7.59
2006	15.27	486.76	498.60	11.85
2007	17.30	545.60	532.64	-12.96
2008	18.60	543.72	554.40	10.69
2009	18.68	530.15	555.80	25.65
2010	16.43	522.53	518.13	-4.39

Table 4.24 WI Values on *Tencha* Productivity (Kg/Ha)

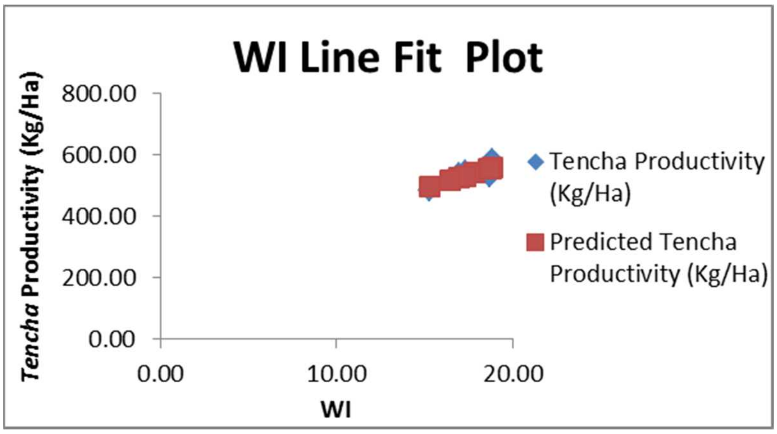


Figure 4.10 WI Values Line Fit Plot on *Tencha* Productivity (Kg/Ha)

Shown in table 4.25 it was apparent that the regression analysis between WI values with tea productivity does not resulted in any correlations.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.657[a]	.432	.351	35.50977

a. Predictors: (Constant), WI

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	6713.518	1	6713.518	5.324	.054[a]
	Residual	8826.608	7	1260.944		
	Total	15540.126	8			

a. Predictors: (Constant), WI
b. Dependent Variable: Tea_Productivity_KgHa

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	362.703	178.114		2.036	.081	-58.470	783.877
	WI	23.262	10.081	.657	2.307	.054	-.577	47.100

a. Dependent Variable: Tea_Productivity_KgHa

Table 4.25 Regression Result for WI Values on Tea Productivity (Kg/Ha) (2002-2010)

Using the calculated WI values from the two monitoring locations (table 4.26), the *tencha* productivity (Kg/Ha) on those locations could be predicted using the formula tencha productivity (Kg/Ha) = 243.040 + (16.740 x WI Value). The predicted tencha productivity for Koyama-en is 537.16 Kg/Ha, while for Shichimei-en is 535.77 Kg/Ha.

	Koyama-en	Shichimei-en
3a	9.72	9.21
3b	14.52	15.40
3c	17.20	17.25
4a	19.67	19.31
4b	20.88	20.70
4c	23.43	23.05
WI	17.57	17.49

Table 4.26 WI Values on Koyama-en and Shichimei-en (2014)

4.6 Chapter Summary

In relation with Research Question 2: "How can we modify the bio-climatic indicators commonly used in winegrape terroir for utilization in Uji Area tea cultivation?" the findings are:

- **Heliothermal Index (HI)** in Uji Tea cultivation needs to be calculated based on the thermal value between early February (2a) (start of cultivation intervention) to early May (5a) (harvest). Based on regression analysis HI values in the category **Temperate Warm** would affect the total first flush **tea productivity (Kg/Ha)**.
- **Combination of HI Values and Mean Precipitation (mm)** would provide **better regression fit for tea productivity (Kg/Ha).**
- **Cool Night Index (CI)** in Uji Tea cultivation need to be calculated based on average minimum temperature from early January (1a) (start of tea plants metabolism) to late April (4c) (end of leaf maturation period).

  Based on regression analysis CI values in the category **Temperate Nights** would affect the first flush ***gyokuro*** **productivity (Kg/Ha)**. **CI Values also affect tea productivity (Kg/Ha)**.

- **Humidity Index (Hum-I)** which is calculated from early February (2a) to early May (5a) resulted in **negative correlation with the tea productivity**, although from analysis it was evident that **combination** of HI values, Mean Precipitation, CI values and Hum-I values **would affect the first flush tea productivity (Kg/Ha)**.
- **Warm Day Index (WI)** in Uji Tea cultivation need to be calculated based on average maximum temperature from early March (3a) (appearance of leaf buds) to late April (4c) (end of leaf maturation period). WI values in the category **Temperate Days** would affect the total first flush ***tencha*** **productivity (Kg/Ha)**.
- **Bio-Climatic Indicators** commonly used in **winegrape terroirs** have to be reformulated and calculated according to the tea cultivation process cycle (figure 4.11). The modified indicators are the Heliothermal Index (HI), Cool Night Index (CI) and Humidity Index (Hum-I) as a proxy for Dryness Index, leading on to the development of the Warm Day Index (WI), this last being derived from Cool Night Index.

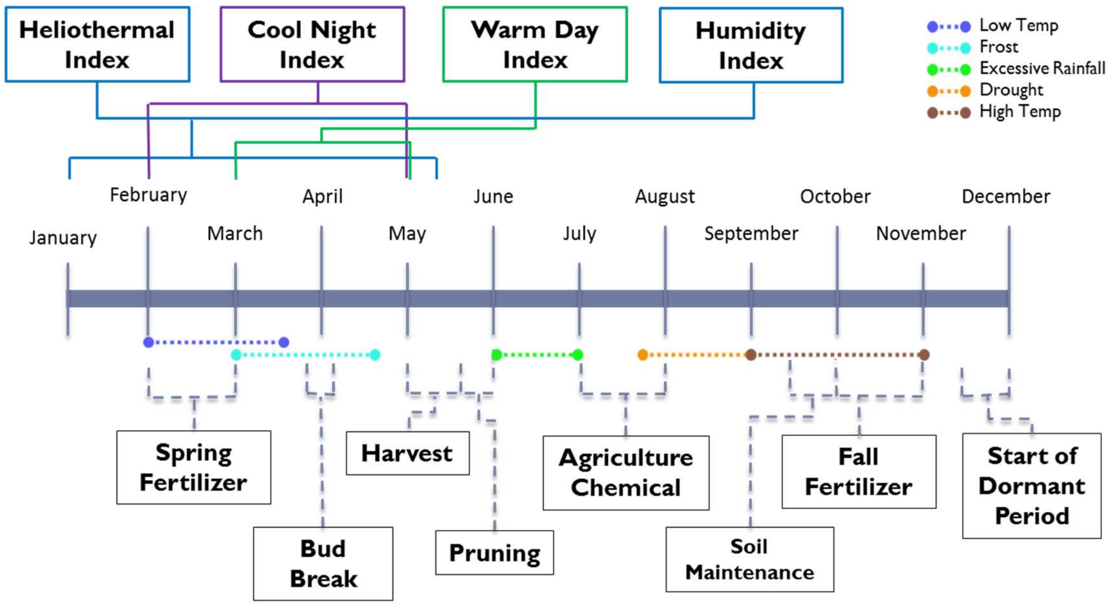


Figure 4.11 Bio-Climatic Indicators and Climatic Events Affecting Plant Phenology in the Uji Tea Cultivation Process

CHAPTER 5

SUSTAINABILITY OF TEA CULTIVATION IN UJI AREA

5.1 Bio-Climatic Indicators for Sustainability of Tea Cultivation in Uji Area

As discussed in the previous chapter, the application of bio-climatic indicators in Uji Area would be beneficial in providing precision agriculture knowledge to the tea growers, in the form of detailed climatic information analysis. Thus combined with the tea grower's knowledge on tea cultivation, applying the indicators would enable assessment which would help the farmers to select effective cultivation intervention types as well as to decide on optimal cultivation intervention timing in order to achieve the desired plant responses. These interventions are important for maintaining or improving the tea production quantity or quality.

Based on an analysis of the results from the social survey especially on the guidelines question 6) on Utilization of Precision Agriculture, it was found that most of the tea growers (67%) rely on external sources for obtaining climatic information (figure 5.1). However, this information does not precisely represent the micro-climatic conditions of their tea plantation. Only five tea growers or 33 percent of the interviewed tea growers utilized climate monitoring tools such as conventional thermometers or digital thermometers in their tea plantations.

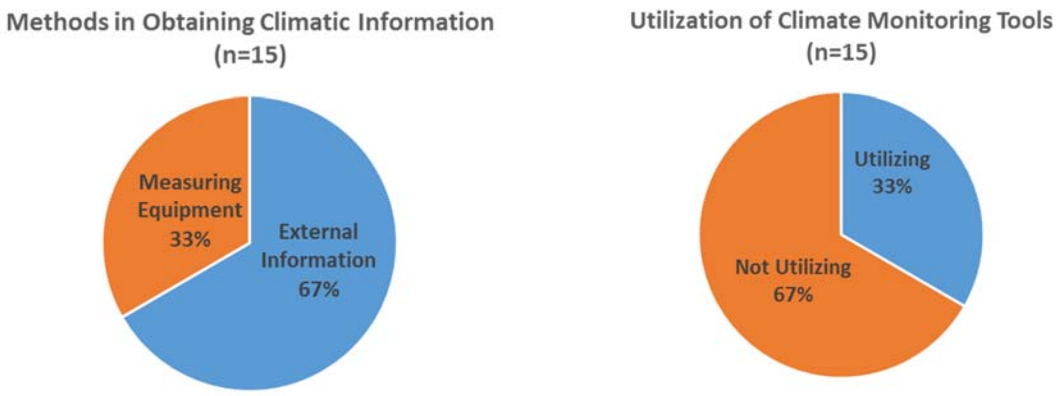


Figure 5.1 Sources of Climatic Information

Analysis of bio-climatic indicator values requires the tea growers to directly monitor their tea plantation, further increasing their awareness on climatic issues. This would also provide prediction on how significant the changes in the micro-climatic condition are and how they will affect the tea cultivation process. Through observation of the moving average values of Heliothermal Index, Cool Night Index and Warm Day Index, the tea growers would be able to response swiftly and actively with sudden changes in climatic conditions.

5.1.1 Heliothermal Index

Based on the Heliothermal Index values the tea growers would be able to predict the tea productivity in a certain plantation area and, through this index, they would obtain more insight into the land selection for future tea plantation expansion/relocation, as well as selecting suitable tea cultivars for the target area. In combination with the mean precipitation data, tea growers would be able to predict the level of tea productivity in a certain area.

Shown in table 5.1 and illustrated in figure 5.2 is the moving average for HI values from 2002 to 2010 while precipitation moving average values is shown in table 5.2 and figure 5.3. Observation of these moving average values would provide real time information on HI values anytime during the cultivation period. Thus using the prediction formula the tea growers would be able to estimate the tea productivity level on those periods, before conducting any cultivation interventions based on CI and WI values.

	2002	2003	2004	2005	2006	2007	2008	2009	2010
2a	-3.80	-2.30	-3.30	-3.55	-4.45	-1.10	-4.75	-1.75	-2.30
2a-2b	-7.50	-6.35	-3.50	-6.15	-6.30	-2.00	-8.65	-1.85	-5.20
2a-2c	-8.90	-5.35	-2.00	-9.65	-6.90	-1.25	-11.40	-2.15	-0.85
2a-3a	-11.40	-5.60	-3.85	-10.05	-7.30	0.40	-12.25	-1.60	-0.25
2a-3b	-11.20	-1.10	-0.55	-10.50	-8.60	-2.20	-7.40	1.70	3.25
2a-3c	-7.95	2.35	2.80	-9.05	-7.65	1.75	-3.35	3.70	3.35
2a-4a	-1.60	10.15	8.60	-2.10	-4.15	5.35	2.05	9.20	9.50
2a-4b	6.70	18.15	19.85	5.50	1.20	12.20	9.35	20.70	14.85
2a-4c	13.15	27.80	29.05	16.85	7.50	21.85	19.90	28.15	20.85
2a-5a	23.65	38.95	41.05	28.30	19.50	33.60	32.65	39.55	33.65

Table 5.1 HI Moving Average Values (2002-2010)

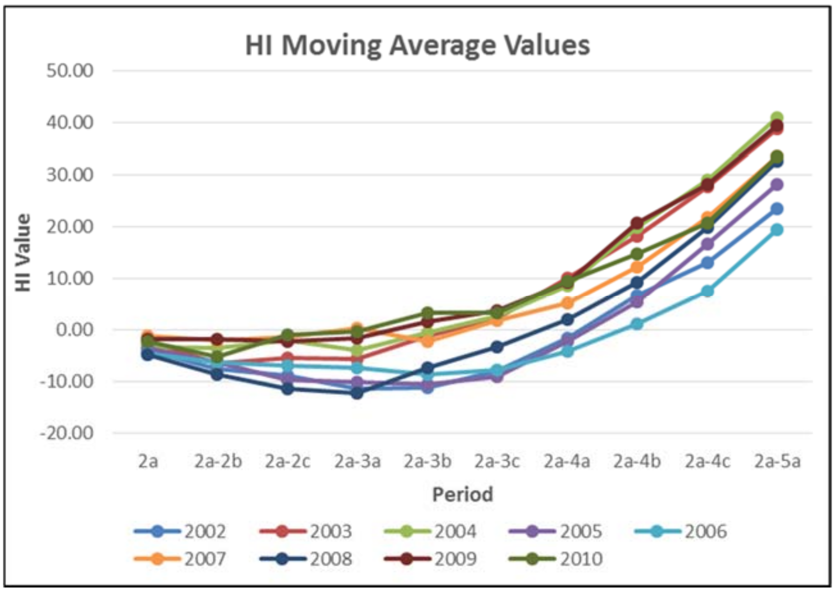


Figure 5.2 HI Moving Average Values (2002-2010)

	2002	2003	2004	2005	2006	2007	2008	2009	2010
1a-1b	31.45	17.35	11.95	20.10	18.90	11.40	11.95	12.50	4.40
1a-1c	44.07	36.23	8.17	14.20	14.30	7.70	17.80	31.93	12.87
1a-2a	42.30	30.93	8.40	14.93	20.85	7.80	21.78	27.30	18.55
1a-2b	34.04	31.62	7.52	21.26	24.72	14.96	18.96	32.56	23.90
1a-2c	35.73	30.17	14.88	18.87	26.40	16.37	21.38	36.35	31.62
1a-3a	37.10	36.27	13.41	18.17	29.59	15.63	20.71	36.80	32.77
1a-3b	34.01	34.43	14.76	20.89	32.26	15.34	25.55	41.43	35.16
1a-3c	33.46	34.73	21.86	23.50	32.23	18.53	27.14	39.40	39.27
1a-4a	30.36	36.89	23.72	21.41	35.53	17.66	32.07	37.48	44.08
1a-4b	29.57	35.83	26.89	22.62	38.15	18.55	35.86	37.29	45.56
1a-4c	29.10	40.23	26.24	20.95	35.19	18.10	34.13	38.83	51.87
1a-5a	29.67	42.09	30.12	24.28	36.72	20.81	33.52	39.15	49.57

Table 5.2 Precipitation Moving Average Values (2002-2010)

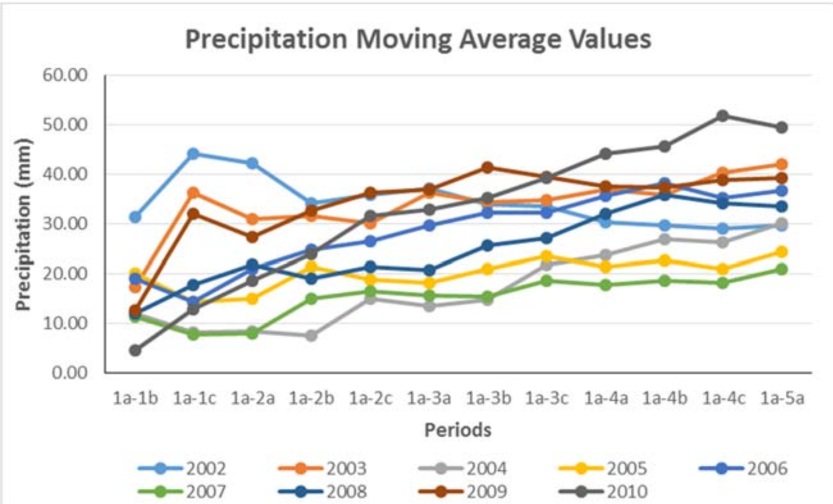


Figure 5.3 Precipitation Moving Average Values (2002-2010)

5.1.2 *Cool Night Index and Humidity Index*

Analysis of the Cool Night Index values would be useful for the tea growers to plan and decide effective cultivation intervention timing, such as for predicting optimal timing in fertilizer application, deciding suitable timing to utilize the leaf cover as well as frost protection system, and, in addition, enabling the tea growers to precisely predict the first flush tea productivity as well as *gyokuro* weight. Through observation of CI moving average values (table 5.3 and figure 5.4) and mean humidity values in early February (2a) to Early May (5a) (table 5.4; figure 5.5), the tea growers would be able to decide optimal timing for cultivation intervention, where the interventions are aimed at adjusting the CI values towards its desired level.

	2002	2003	2004	2005	2006	2007	2008	2009	2010
1a	0.00	-1.00	0.40	-0.40	-1.50	0.90	0.50	1.40	0.50
1a-1b	-1.45	0.65	0.55	0.10	-0.40	0.30	0.40	0.30	-0.30
1a-1c	-1.07	0.50	-0.23	-0.07	-0.57	0.07	0.50	0.57	-0.07
1a-2a	-0.90	0.25	-0.43	0.13	-0.58	0.08	0.23	0.33	0.15
1a-2b	-1.08	-0.04	-0.50	0.36	-0.28	0.18	0.02	0.56	0.20
1a-2c	-1.08	-0.04	-0.50	0.36	-0.28	0.18	0.02	0.56	0.20
1a-3a	-0.79	0.44	-0.03	0.16	0.26	0.46	-0.06	1.31	1.89
1a-3b	-0.68	0.78	0.24	0.28	0.35	0.34	0.63	1.50	2.06
1a-3c	-0.12	1.06	0.72	0.57	0.52	0.66	1.04	1.59	2.16
1a-4a	0.35	1.65	1.03	1.01	0.94	1.02	1.50	1.79	2.52
1a-4b	1.01	2.21	1.90	1.61	1.66	1.53	2.25	2.56	3.09
1a-4c	1.46	3.00	2.38	2.25	2.14	2.13	2.81	2.95	3.48

Table 5.3 CI Moving Average Values (2002-2010)

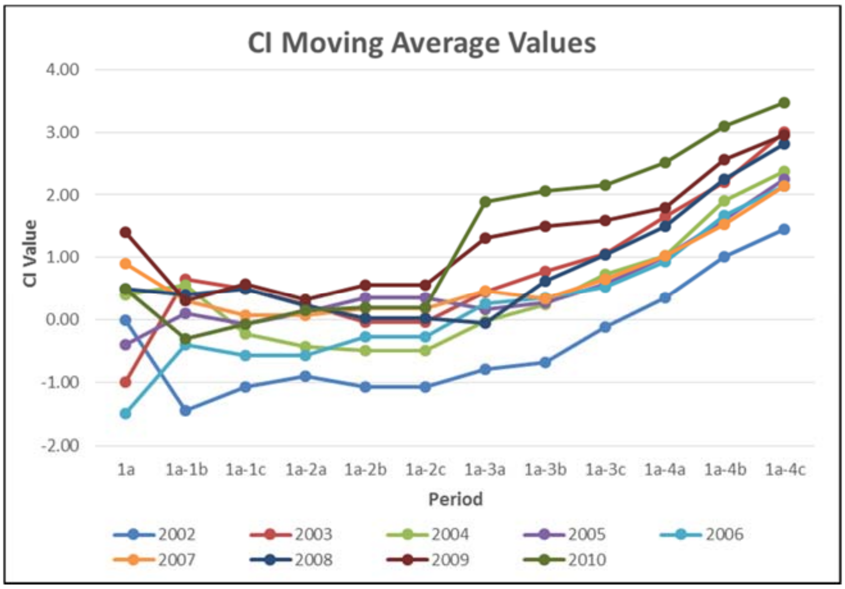


Figure 5.4 CI Moving Average Values (2002-2010)

	2002	2003	2004	2005	2006	2007	2008	2009	2010
2a	76.40	76.10	72.30	70.90	73.80	71.70	82.10	76.40	79.10
2b	67.70	72.10	76.40	75.90	75.80	73.20	75.10	77.40	79.60
2c	72.60	72.00	79.60	69.30	76.00	71.30	74.40	79.90	82.00
3a	69.10	69.40	75.20	71.30	76.90	68.70	75.40	75.70	88.20
3b	67.30	65.10	74.70	73.90	74.10	68.30	73.70	74.90	75.00
3c	67.90	71.30	78.10	72.10	70.50	75.30	73.20	69.10	77.80
4a	66.00	66.00	73.30	65.80	69.60	70.10	72.40	69.20	71.80
4b	63.00	71.10	74.50	67.00	73.60	67.40	78.20	67.70	78.20
4c	67.10	72.00	69.80	61.70	68.10	70.60	71.20	70.10	71.30
5a	76.00	77.10	78.80	69.80	73.80	75.30	70.10	67.50	69.90

Table 5.4 Mean Humidity Values (2002-2010)

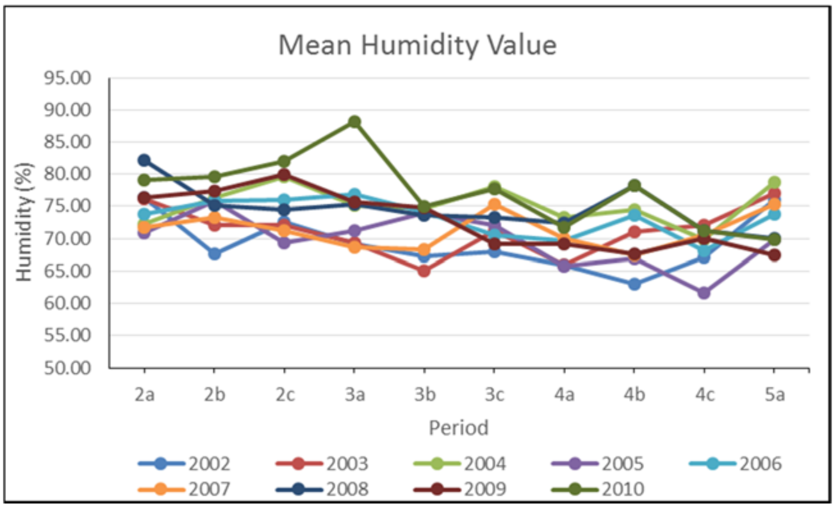


Figure 5.5 Mean Humidity Values (2002-2010)

5.1.3 *Warm Day Index*

From the analysis of Warm Day Index moving average values (table 5.5 and figure 5.6), the tea growers could formulate effective cultivation intervention types such as selection of leaf covering level and types of soil fertilizers. If deemed necessary, the tea growers could conduct interventions which would alter the value of WI, such utilizing watering system. WI values could also be utilized as guidelines to predict the first flush *tencha* yield.

	2002	2003	2004	2005	2006	2007	2008	2009	2010
3a	9.90	12.80	11.00	13.00	12.50	15.30	12.40	13.20	12.40
3a-3b	11.75	15.55	14.10	12.70	11.85	12.75	15.30	15.05	14.75
3a-3c	13.23	16.00	14.87	13.20	12.70	14.37	16.00	15.27	14.10
3a-4a	15.00	17.35	16.08	15.13	13.63	14.98	16.70	16.45	15.50
3a-4b	16.38	18.16	17.86	16.32	14.44	16.10	17.38	18.26	15.94
3a-4c	16.95	18.85	18.75	17.83	15.27	17.30	18.60	18.68	16.43

Table 5.5 WI Moving Average Values (2002-2010)

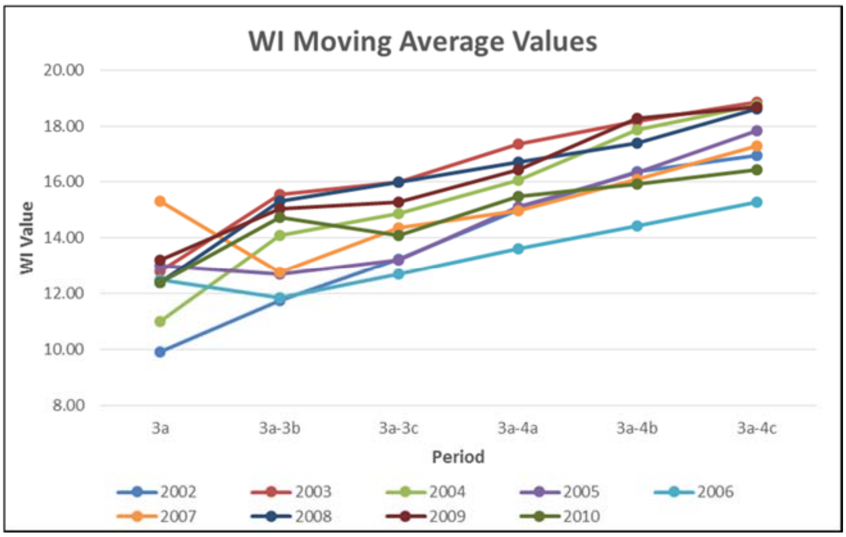


Figure 5.6 WI Moving Average Values (2002-2010)

5.2 Economic Issues

Although the current changes in the micro-climatic conditions in Uji Area do not immediately have any disastrous effects toward the tea cultivation process, it has significantly reduced the tea harvest yield and productivity. With the increasing trend of climatic behavioral changes, in the near future tea growers in Uji Area might not be able to produce tea products which reflect the well-known quality and characteristic of Uji Tea. For generations the Uji Area has been well known as the most famous tea growing region in Japan as well as with its especially distinct tea products. The tea products which are produced inside the Uji Area especially *matcha*, is known to be the benchmark for the highest quality of this tea product in Japan.

Despite having a well-known status, the tea growers in Uji Area are actually facing several other issues apart from the changing climatic conditions encountered in the tea cultivation process. Currently some of the main issues which are faced by the tea growers mostly originate from an economic perspective, where declining sales value and increasing expense in the tea cultivation have slowly affected the tea grower's financial condition.

Shown in table 5.6 and figure 5.7 the total production value of *tencha* has been declining steadily in the past 20 years, whereas in comparison with *gyokuro*, interestingly the latter showed there were no drastic changes in the total value, and in fact it was exhibiting a generally steady value with a few slight changes over the years. As explained in the previous chapter, the tea cultivars used to produce both *tencha* and *gyokuro* are generally the same, and the difference only lies on how the tea cultivation process was conducted. Because the demand for *gyokuro* is relatively stable due to its high price, the tea growers only cultivate tea products into *gyokuro* based on the tea wholesaler's request, whereas the bulk of the production is on *tencha* as the demand is always high.

Year	Tencha Value (Yen)	Gyokuro Value (Yen)
1991	905,280,000	132,810,000
1992	859,600,000	123,380,000
1993	816,640,000	111,000,000
1994	827,936,000	122,160,000
1995	748,494,000	127,236,000
1996	796,851,000	139,572,000
1997	795,859,000	96,150,000
1998	744,646,000	91,168,000
1999	725,700,000	92,769,000
2000	663,120,000	84,769,000
2001	654,740,000	83,698,000
2002	619,269,000	79,164,000
2003	543,096,000	85,984,000
2004	511,368,000	81,464,000
2005	521,592,000	83,904,000
2006	473,712,000	74,784,000
2007	528,531,000	81,796,000
2008	521,311,000	81,365,000
2009	497,718,000	109,184,000
2010	496,620,000	109,880,000
2011	507,074,000	110,664,000
2012	503,323,000	110,472,000
2013	520,822,000	111,883,000

Source: Kyoto Prefecture, 2015

Table 5.6 *Tencha* and *Gyokuro* Production Values (Yen) in Uji Area (1991-2013)

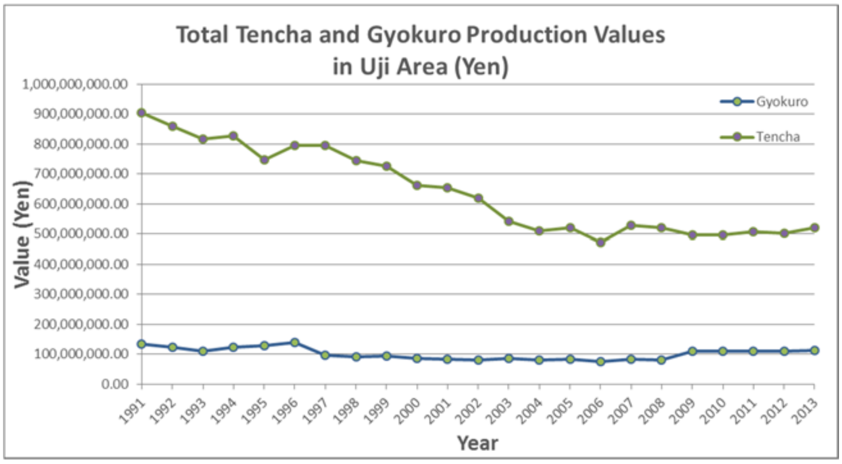


Figure 5.7 *Tencha* and *Gyokuro* Production Values (Yen) in Uji Area (1991-2013)

Year	Tencha Weight (Kg)	Gyokuro Weight (Kg)
1991	56,580	13,281
1992	53,725	12,338
1993	51,040	11,104
1994	51,746	12,216
1995	41,749	10,603
1996	44,335	11,631
1997	49,806	9,615
1998	53,189	11,396
1999	49,200	11,560
2000	44,957	10,563
2001	44,394	8,890
2002	41,428	8,890
2003	45,258	10,748
2004	42,614	10,183
2005	43,466	10,488
2006	39,476	9,348
2007	44,139	10,224
2008	43,443	10,171
2009	41,670	13,648
2010	41,175	13,735
2011	42,604	13,833
2012	42,503	13,809
2013	45,274	13,985

Source: Kyoto Prefecture, 2015

Table 5.7 *Tencha* and *Gyokuro* Production Weight (Kg) in Uji Area (1991-2013)

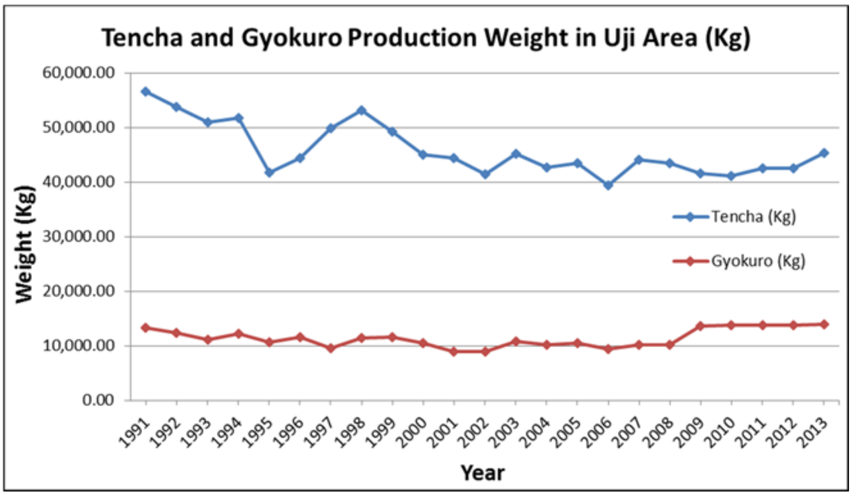


Figure 5.8 *Tencha* and *Gyokuro* Production Weight (Kg) in Uji Area (1991 to 2013)

From the comparisons between the total *tencha* and *gyokuro* production weight (table 5.7 and figure 5.8), it could be identified that similarly to the sharp decline in *tencha* value, the production weight has also decreased. Whereas on the other hand the total *gyokuro* production weight appeared to have similar trend with its values. Further analysis showed in table 5.8 and figure 5.9 clearly identified a continuous declining trend for the price of *tencha* per kilogram, but because the price of *gyokuro* per kilogram is pegged with that for *tencha*, (note that, as previously explained, the cultivation of both tea types are actually conducted at the same time) although *gyokuro* weight remains relatively constant (in contrast to *tencha*, which has fallen somewhat), its price has dropped with that of *tencha*.

Year	Tencha Price (Yen/Kg)	Gyokuro Price (Yen/Kg)
1991	16,000	10,000
1992	16,000	10,000
1993	16,000	9,996
1994	16,000	10,000
1995	17,928	12,000
1996	17,973	12,000
1997	15,979	10,000
1998	14,000	8,000
1999	14,750	8,025
2000	14,750	8,025
2001	14,748	9,415
2002	14,948	8,905
2003	12,000	8,000
2004	12,000	8,000
2005	12,000	8,000
2006	12,000	8,000
2007	11,974	8,000
2008	12,000	8,000
2009	11,944	8,000
2010	12,061	8,000
2011	11,902	8,000
2012	11,842	8,000
2013	11,504	8,000

Source: Kyoto Prefecture, 2015

Table 5.8 *Tencha* and *Gyokuro* Price (Yen/Kg) in Uji Area (1991-2013)

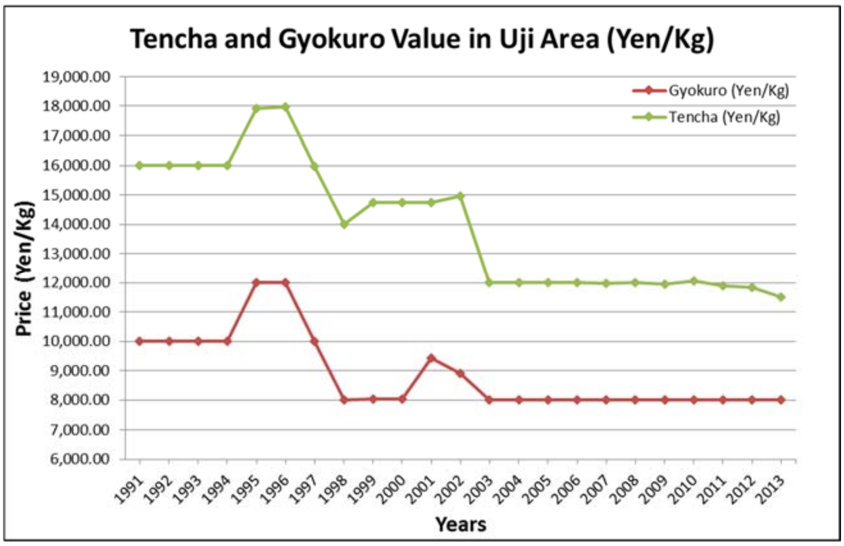


Figure 5.9 *Tencha* and *Gyokuro* Price (Yen/Kg) in Uji Area (1991-2013)

Based on the social survey it was found that there heavy droughts occurred in 1994, which caused significant drop in the tea harvest yield in 1995, thus directly triggering a surge for both *tencha* and *gyokuro* price per kilogram (figure 5.9). In the following years after the sudden drop, the tea production yield slowly increased and was able to surpass its previous yield in 1998 (figure 5.8), which interestingly further decreased the price of *tencha* and *gyokuro*, surpassing its previous values prior to the price surge (figure 5.8).

This event shows that, based on the supply and demand relationship, it was highly likely that the tea wholesalers had overstocked their supplies of both *tencha* and *gyokuro* with purchases from outside Uji Area. The probable motive behind this action was the wholesalers' decision to ensure that there was enough supply during the period when Uji Area tea production fell. This action must be viewed in relation to the definition of Uji Tea, which aims at protection of this brand, and the harsh realities of the tea market, which operated against the background of uncertainties in production brought about by sudden climatic changes

In the year 2002 there were records of frost events and low temperature conditions which caused another decline in the harvest yield, which directly caused a slight price surge on *tencha* and *gyokuro* value. Faced with these conditions, it was evident that the tea wholesalers further increased their tea supply that was produced from outside Uji Area. In the following year after the yield drop in 2002, most of the tea wholesalers have already increased their purchases steadily from tea growers outside of Uji Area. This was also affected by an indication of increasing demand for *matcha* products in the Japanese market.

From these findings it could be seen that, despite the fact that the tea harvest yield was able to return to, or even surpass, its original yield after several drops (figure 5.8), it was apparent that the price per kilogram for *gyokuro*, and especially for *tencha*, was not able to return to its former values. Instead the price kept decreasing further although, interestingly, the price of *gyokuro* in 2003 was able to return to its previous values. It was also evident that the tea wholesalers have been increasing their *tencha* supply from the neighboring area such as Uji Tawara and Watsuka, where there is an identifiable increase in the *tencha* production weight (Kg) (table 5.10; figure 5.9) as well as the total *tencha* production values (table 5.9; figure 5.8) especially for the tea produced from Watsuka Area.

Year	Uji Tawara Tencha (Yen)	Watsuka Tencha (Yen)	Uji Tawara Gyokuro (Yen)	Watsuka Gyokuro (Yen)
1991	126,000,000	17,680,000	124,200	
1992	176,000,000	26,840,000	88,900	
1993	156,100,000	26,304,000	98,000	
1994	149,300,000	21,024,000	112,600	
1995	295,800,000	40,169,000	122,100	
1996	523,296,000	418,937,000	113,571	
1997	412,538,000	634,816,000	100,486	625
1998	343,959,000	400,881,000	98,203	
1999	245,744,000	361,654,000	127,173	
2000	398,170,000	649,741,000	126,637	
2001	355,405,000	565,343,000	107,895	
2002	494,407,000	874,945,000	252,665	
2003	386,903,000	893,110,000	307,716	1,810
2004	287,637,000	877,422,000	317,576	5,903
2005	439,190,000	1,049,859,000	416,886	10,346
2006	382,350,000	944,459,000	371,681	4,851
2007	304,810,000	935,194,000	420,757	7,187
2008	398,769,000	1,019,276,000	420,811	13,252
2009	373,193,000	977,604,000	414,861	20,541
2010	281,046,000	949,570,000	348,850	21,769
2011	368,605,000	1,190,027,000	354,589	21,248
2012	612,899,000	1,568,316,000	344,003	18,643
2013	503,374,000	1,321,173,000	489,419	33,760

Source: Kyoto Prefecture, 2015

Table 5.9 *Tencha* and Gyokuro Production Values (Yen) in Uji Tawara and Watsuka Area (1991-2013)

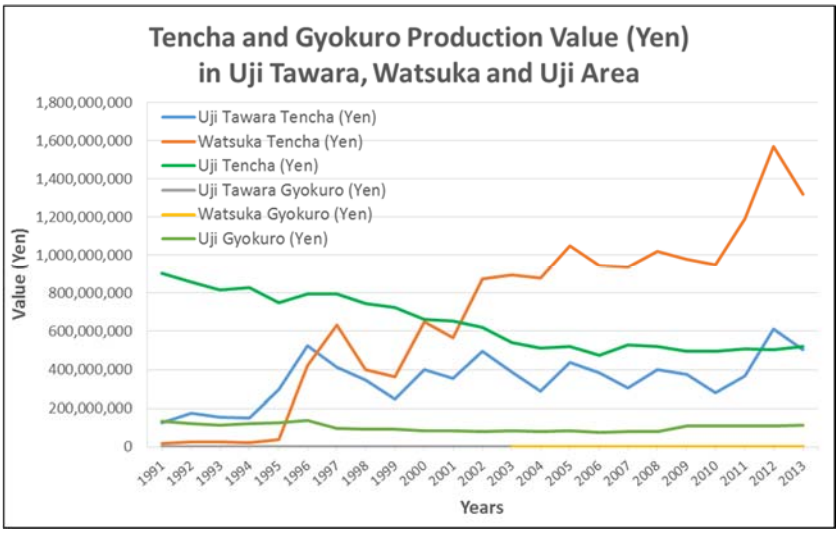


Figure 5.10 *Tencha* and *Gyokuro* Production Values (Yen) in Uji Tawara, Watsuka and Uji Area (1991-2013)

Year	Uji Tawara Tencha (Kg)	Watsuka Tencha (Kg)	Uji Tawara Gyokuro (Kg)	Watsuka Gyokuro (Kg)
1991	20,330	3,400	18,200	
1992	27,100	4,880	14,800	
1993	26,130	5,220	18,140	
1994	27,170	5,850	20,440	
1995	46,010	6,376	21,322	
1996	86,804	57,481	22,687	
1997	80,194	113,812	20,891	165
1998	90,925	108,019	25,843	
1999	45,052	71,657	25,791	
2000	84,006	175,663	25,687	
2001	85,760	173,618	25,618	
2002	144,567	230,357	58,855	
2003	109,520	246,854	58,379	439
2004	81,306	249,982	62,762	1,229
2005	119,761	275,411	87,192	2,403
2006	122,437	264,476	76,888	1,058
2007	101,044	262,182	93,668	1,568
2008	129,253	291,319	87,160	2,432
2009	133,382	310,473	98,430	3,483
2010	110,959	328,713	97,205	4,486
2011	115,471	340,988	95,670	3,981
2012	188,827	445,774	80,250	3,573
2013	246,891	563,183	106,071	6,299

Source: Kyoto Prefecture, 2015

Table 5.10 *Tencha* and *Gyokuro* Production Weight (Kg) in Uji Tawara and Watsuka Area (1991-2013)

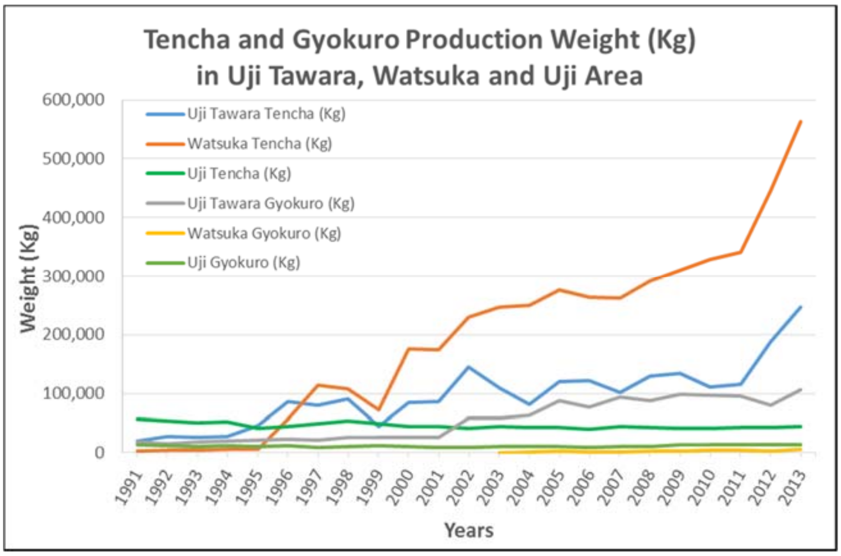


Figure 5.11 *Tencha* and *Gyokuro* Production Weight (Kg) in Uji Tawara, Watsuka and Uji Area (1991-2013)

Year	Uji Tawara Tencha (Yen/Kg)	Watsuka Tencha (Yen/Kg)	Uji Tawara Gyokuro (Yen/Kg)	Watsuka Gyokuro (Yen/Kg)
1991	6,198	5,200	6,824	
1992	6,494	5,500	6,007	
1993	5,974	5,039	5,402	
1994	5,495	3,594	5,509	
1995	6,429	6,300	5,726	
1996	6,028	7,288	5,006	
1997	5,144	5,578	4,810	2,793
1998	3,783	3,711	3,800	
1999	5,455	5,047	4,931	
2000	4,740	3,699	4,930	
2001	4,144	3,256	4,212	
2002	3,420	3,798	4,293	
2003	3,533	3,618	5,271	1,806
2004	3,538	3,510	5,060	1,751
2005	3,667	3,812	4,781	1,901
2006	3,123	3,571	4,834	1,780
2007	3,017	3,567	4,492	1,777
2008	3,085	3,499	4,828	1,742
2009	2,798	3,149	4,215	1,567
2010	2,533	2,889	3,589	1,437
2011	3,192	3,490	3,706	1,735
2012	3,246	3,518	4,287	1,749
2013	2,039	2,346	4,614	1,165

Source: Kyoto Prefecture, 2015

Table 5.11 *Tencha* and *Gyokuro* Price (Yen/Kg) in Uji Tawara and Watsuka Area (1991-2013)

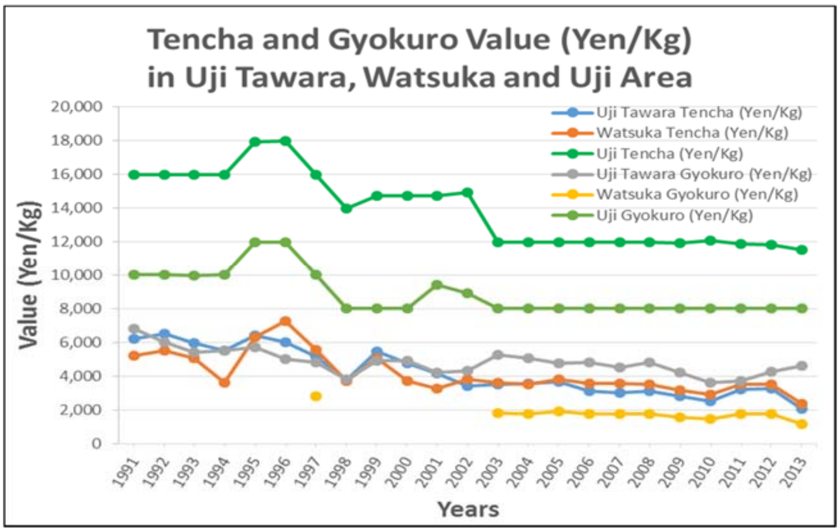


Figure 5.12 *Tencha* and *Gyokuro* Value (Yen/Kg) in Uji Tawara, Watsuka and Uji Area (1991-2013)

As shown in table 5.10 and figure 5.9, although there is significant increase of total *tencha* production weight and its total value (table 5.9; figure 5.8), the actual price per kilogram are actually decreasing (table 5.11; figure 5.10). This is most likely caused by *tencha* production increase, which affects the supply and demand interactions. It could also be observed that gyokuro production was started in Watsuka Area intensively from 2003, corresponding with the drop of production yield in Uji Area.

Based on anecdotal information it is known that tea wholesalers in Uji Area prefer to purchase tea leaves from tea growers in a bulk quantity, which usually means purchasing almost all of the tea produced by a tea grower. In the case of tea leaves produced in other regions (i.e. Uji Tawara, Watsuka, Shigaraki, Tsuchiyama, etc.), although the quality might not be comparable to the tea produced in Uji Area, the production yield is higher but with a notably lower selling price per kilogram as observed in Uji Tawara and Watsuka Area. From these issues it is clear that the Uji Tea growers are faced with not only tea cultivation issues because of climatic conditions but also price competition, as the tea produced in neighboring regions have lower prices compared to Uji Area.

Most of the harvested tea leaves from Uji Area are sold to tea wholesalers, which under the definition of Uji Tea, can freely blend the tea leaves from Uji Area with the tea leaves produced from other regions, and market the products as Uji Tea. There are also some indications that demand for high quality tea is in the declining trend, although the demand for *matcha* flavored sweets are increasing, therefore tea sellers prefer to use cheaper tea leaves compared to high quality leaves which are produced in Uji Area.

Faced with these financial issues, the analysis result of the social survey especially with respect to the guidelines question 7) on Socio-Economic and Environmental Issues; showed that most tea growers in Uji Area expressed that it has become increasingly difficult to support the financial condition of their household only with income from tea cultivation. Shown in figure 5.13 apart from the 77 percent that expressed apparent pressures in their financial condition, there were more daunting issues reflected in the answers, where around 23 percent have mentioned that it is no longer possible to support their household only with the income from tea cultivation. Therefore beside tea cultivation these growers have also produce and distribute their own tea products. Despite knowing the latent danger of climate change effects, not all of the tea growers were fully interested in investing their resources to countermeasure climate change effects, mostly due to financial constraints.

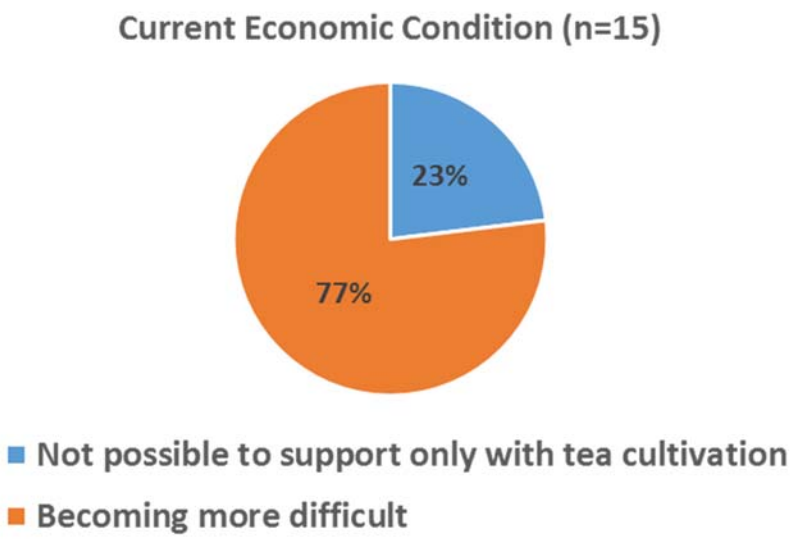


Figure 5.13 Current Economic Conditions of Uji Tea Growers

5.3 Social Issues

Gradually the current existing economic issues will be further worsened by climate changes effects, creating many uncertainties in the future of the tea cultivation industry. This condition has made the younger generation in the tea growers family to become less interested in continuing their family business. Already faced with the existing economic uncertainties, a young tea grower would need to understand the intricate and complex traditional tea cultivation process in order to continue their family business.

These requirements further increase the challenges of entering the tea industry. Thus, evidently, securing a successor in the tea cultivation business have become an issue in Uji Area. Although at the moment none of these issues has yet to dominate, as the population ages this would become a serious issue which evidently will affect the sustainability of the area as a prominent tea growing region.

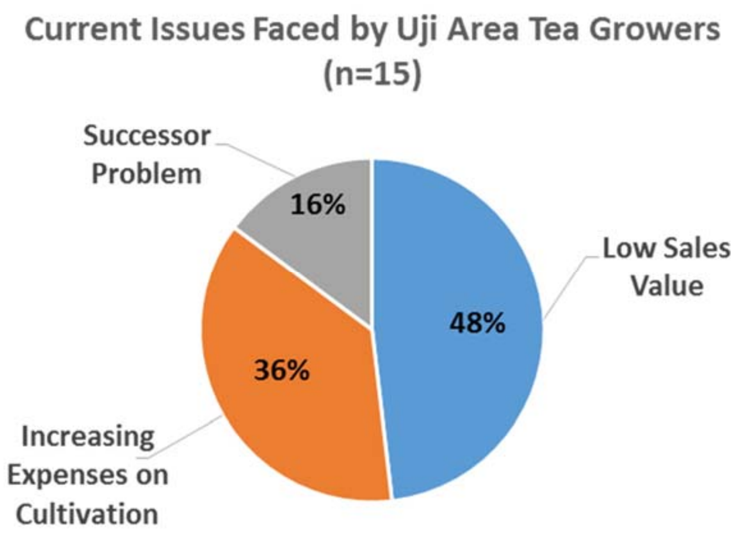


Figure 5.14 Current Issues Faced by Uji Area Tea Growers

If these issues are not properly addressed, it would not be long until the tea products which are cultivated in Uji Area would disappear. This also means that the disappearance of tea production from Uji would be preceded by the collapse of the social structure of the tea grower's community, which now sustains this production. Although protecting Uji Area as a tea growing region is important, much more critical effort would need to be placed on preserving traditional Uji Tea cultivation knowledge, which has been passed down for generations.

5.4 Chapter Summary

In relation with Research Question 3: "How do changes in bio-climatic indicators values signal cultivation interventions to overcome the impact of changing climate factors and enhance yield and value?" the findings are:

- Heliothermal Index (HI), Cool Night Index (CI), Humidity Index (Hum-I) and Warm Day Index (WI) would provide input and information to the tea growers where:
    - HI values are useful for land selection as well as cultivars selection for tea cultivation and, when combined with the mean precipitation values the tea productivity level could also be predicted with considerable accuracy.
    - CI values would be useful to predict optimal cultivation intervention timing, such as time to fertilize, utilize leaf cover and frost protection system. CI values could be utilized to predict *gyokuro* production.
    - Hum-I values in combination with HI, Precipitation and CI would be very useful to increase the accuracy in predicting tea productivity level.
    - WI values can be utilized to select the most effective type of cultivation

intervention, such as selection of leaf covering level and types of soil fertilizers. WI values could also be used to predict *tencha* weight.

- Through observation of these bio-climatic indicators moving averages values, decisions on cultivation intervention timing and selecting types of interventions could be made swiftly and effectively.
- Bio-climatic indicators values provide precision information to the tea growers where the optimal timing and intervention actions conducted could lead to the formulation of new cultivation intervention methods. These new intervention methods would allow the tea growers to swiftly adapt to changing climatic factor and also contribute to maintaining and enhancing the yield and value of tea production. The model indicating this, incorporating the findings explained thus far, could be seen in figure 5.15 below.

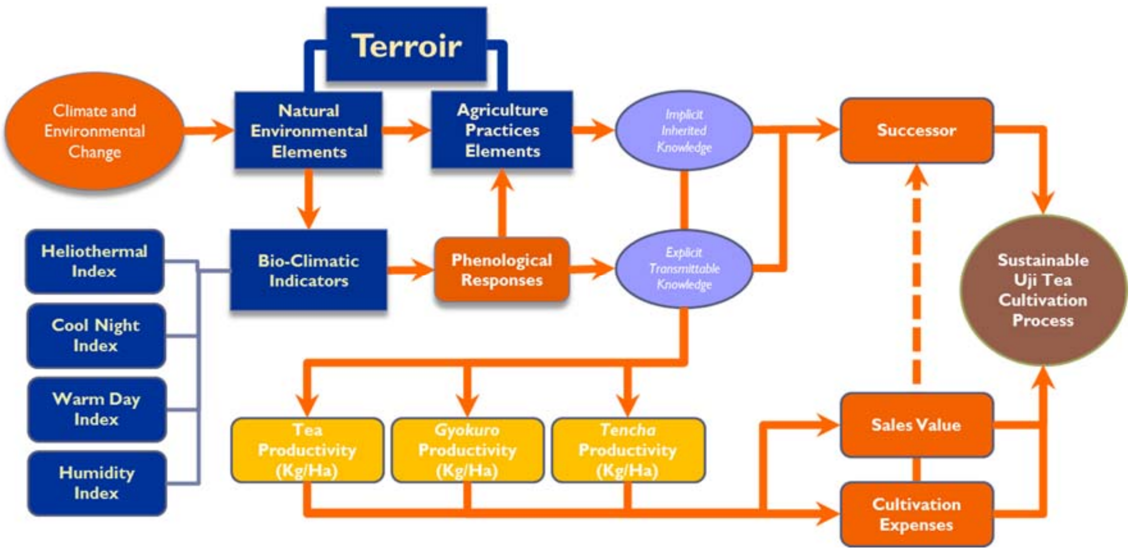


Figure 5.15 Bio-Climatic Indicators for Uji Area Sustainability

CHAPTER 6

DISCUSSION AND CONCLUSION

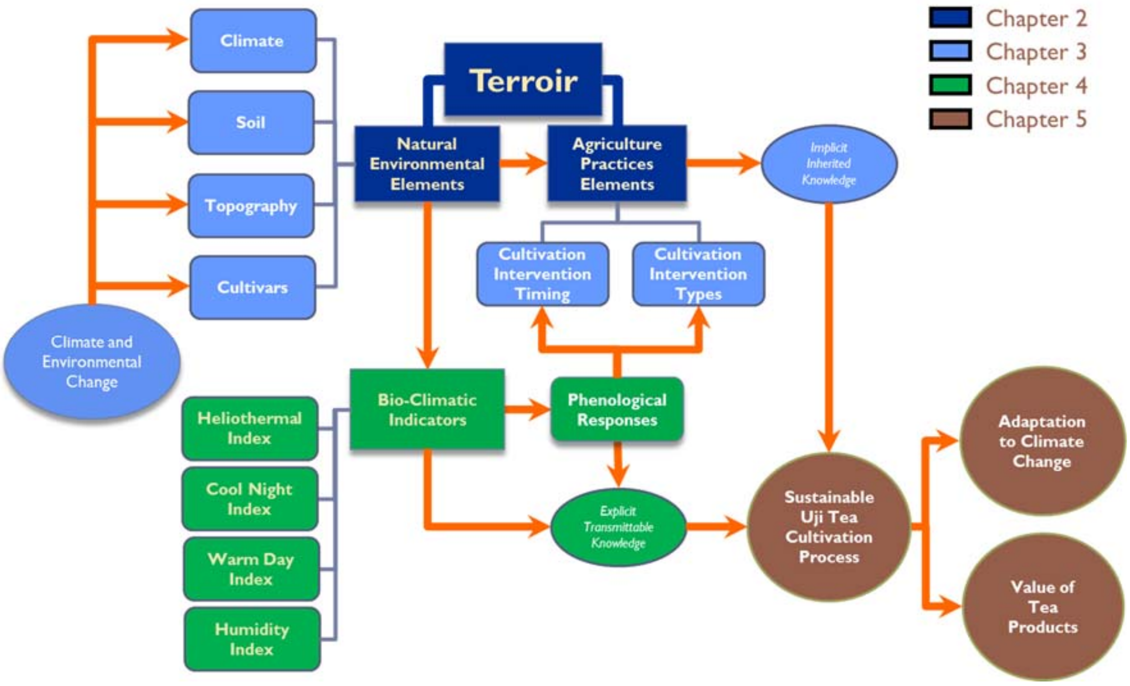


Figure 6.1 Application of Bio-Climatic Indicators for Tea Cultivation in Uji Area

6.1 Research Originality

This study has utilized a new approach indicated in the research framework (figure 1.1 and figure 6.1) which has never been implemented in the tea cultivation industry, despite its long history and the fact it is the man-made beverage that is most consumed in the world (water being the only other drink that exceeds it). Derived from the winegrape terroirs, in the methodology adopted in this study, the concept of terroir has been further defined this research, where the terroir is elaborated into two elements, viz. the Natural Environment Element and Agricultural Practices Element, whereas each element consist of several important factors indicated in figure 2.2.

During observation of the terroir elements, especially with respect to the climatic factors, it was evident that the changing climatic factors have been affecting the tea cultivation process in Uji Area, as discussed in chapter 3 it was observed that fluctuations in the air temperature, especially low air temperature have caused decline in the harvest yield. It was also reported, based on the social survey conducted in this study, that fluctuations in the air temperature directly affect the quality of leaf fiber, which is most likely to affect the first flush harvest quality.

Based on the tea cultivation process analysis and observation in Uji Area, important factors in each terroir elements were identified, where it was found that climatic and soil factors in the Natural Environmental Element category are very important for the tea cultivation. Changes in these two factors will directly correspond with the Agriculture Practices Elements category, where the grower's response is represented by factors such as selection of the types and timing of cultivation intervention. Based upon these findings, several important bio-climatic indicators were selected, viz. Heliothermal Index, Cool Night Index, Humidity Index and Warm Day Index. These indices, adopted from those developed for winegrape cultivation, were reformulated and recalculated for application in tea cultivation in Uji Area, based on the analysis of the cultivation process and the phenological response of the tea plants in the locality.

This study is the first documented application of the afore-mentioned bio-climatic indicators for the tea cultivation in Uji Area, the oldest tea producing region in Japan, thus opening up the possibility for the indicators to be utilized in general tea cultivation elsewhere as well. Through analysis of the bio-climatic indicators tea growers would be able to further understand and receive information about the micro-climatic impacts on their tea plantations in real time, as well as enabling them to predict the harvest yield based on the current bio-climatic indicator values. The study has highlighted the importance of gathering precise climatic information at the crop growing locality, as close to real-time as possible, to enable the producers in the region strengthen their resilience to change.

6.2 Policy Implications

Currently Uji Area tea growers to some extent have already understood the impact of rapid climatic changes, especially its adverse effects towards the tea cultivation. Despite knowing the potential dangers of climatic impacts in the future, the tea growers are less worried about the worst possible scenario, even though indications are that they are heading towards this, because they are facing several issues other than climatic change. Currently some of the main issues faced by the tea growers mostly originate from economic concerns, where declining sales value and increasing cultivation expenses have slowly affect the tea grower's financial condition.

As a result, this condition has made the younger generation in the tea grower's family to become less interested in continuing their family business because of the economic uncertainties. Before they could be involved in the tea cultivation, young tea growers would encounter challenges in understanding the intricate and complex traditional cultivation and distribution processes in Uji Area tea cultivation, thereby further increasing their reluctance to enter the tea cultivation industry. Thus, from the social survey conducted in this study, it is evident that securing a successor has also become an important issue in Uji Area, despite its reputation as a premier tea producing locality in Japan.

Explained in the previous chapter, the tea growers in Uji Area could utilize the bio-climatic indicators developed from this research viz. the Heliothermal Index, Cool Night Index, Humidity Index and Warm Day Index, to maintain and improve the tea production yield. The combination of the tea growers inherited tea cultivation knowledge, with the precision information from bio-climatic indicators values would significantly increase the tea grower's capabilities to effectively select appropriate land plot as well as cultivar (plant variety) for tea cultivation, as well as for decision making in conducting appropriate cultivation interventions, which could further optimize and improve the tea cultivation process.

Currently most of the tea growers in Uji Area obtain climatic information from external sources such as electronic media, newspaper and the internet, which only provides information on a wide meso-climatic scale for the region, which to a certain degree requires corrections to reflect the real micro-climatic condition in each tea plantation. With the current rapid climatic changes, these open source climatic data would not be able to constantly provide precise climatic information, whereas there are also limitations such as time constraints for the tea growers to continuously monitor the micro-climatic conditions on their tea plantation. Without precise information, the tea growers would become less aware about the changes in the tea plantation, and might lead to cultivation intervention decisions which are ineffective and resource consuming. From this analysis it could be argued that it is critical for the local government and agricultural institutions to put more focus on assisting the tea growers to obtain precise micro-climatic condition on their tea plantations.

In order to utilize and calculate the value of bio-climatic indicators, the tea growers would have to constantly monitor and record the changes in the micro-climatic condition, and for these purposes, the tea growers would need to utilize simple precision measurement equipment, or perhaps even more advanced and precise field measurement stations. From the recorded climatic data, calculation of bio-climatic indicator values could be conducted immediately, whereas through these monitoring activities the tea growers would be able to further understand the micro-climatic conditions in their tea plantation and their impacts on the quality of the tea produced. This in turn, would make them becoming more aware of the significance of changing climatic conditions on their livelihood and allow them to swiftly adapt to any of the changes.

The indications from the findings of this study are that through the combined applications of traditional cultivation knowledge and bio-climatic indicators, tea growers would be able to maintain the quantity and quality of the tea products from Uji Area. Thus it could lead to the creation of new product value based on the characteristic of the natural environmental elements. The new product value would emerge in two forms, viz. value internal to the tea plant and value external to it which includes cultivation modalities and their monitoring. The new internal values would likely to emerge as improvement to the tea products' characteristics themselves, such as fragrance, color, taste and health benefit. New external value would come from developing systematic detailed records of the tea cultivation process.

From these records products traceability, safety and quality assurance aspects, which include detailed information on the terroir elements that contribute to the product's characteristics, can be communicated to potential buyers in both wholesale and retail markets. Thus, a combination of these detailed records (external value) and the sensory attributes of the tea itself (internal value) can be used to create a strong brand value for the tea product based on rational evidence-based investigation. These new values of the tea products would create new market demands, thus leading to new economic benefits for the tea growers and their community in Uji Area. This would, in turn, make it easier to find successors within tea growing families and also lower barriers for new entrants attracted by the dynamism and profitability of the sector as detailed below.

The benefits from this combination of internal and external value, initiated by the methodologies shown in this study would provide a foundation for the tea growers to further develop their tea plantations, increasing their production yield as well as the product quality. With a strong economic foundation, the tea grower's community would be able to grow easily, becoming more appealing to the younger generation in the community, and supporting them to become the next generation of Uji tea grower. As previously mentioned, there are several challenges for attracting younger generation to become a full time tea growers, thereby with the economic issues have been taken into account, the next hurdle is for the young tea growers to understand the traditional tea cultivation process in Uji Area.

Utilizing the correlation data from bio-climatic indicators values with the tea cultivation practices, especially on selecting cultivation intervention types and timing, young and less experienced tea growers would be able to quickly comprehend the mechanism of an important cultivation process, as well as understanding how the indicator values will affect the tea production quantity and quality. By securing a successor for continuing tea cultivation practice in their family, it would definitely contribute to the socio-economic benefit of Uji Area, which ultimately ensuring the sustainability of Uji Area as a tea growing region.

6.3 Future Research

Currently the definition of Uji Tea is delineated as a fairly broad geographical perspective, where the tea cultivation area covers the four prefectures surrounding the Uji production area (Kyoto, Nara, Shiga and Mie) in Japan. This definition was adopted in 2006 to increase the production volume of tea commodities which are the tea blends produced by the tea wholesaler in Uji Area. Historically all of the tea wholesaler families in Uji Area were once tea growers who turned into tea wholesalers, where besides conducting tea cultivation they were able to create their own tea blends, which later on became well known to become one of the tea products from Uji Area. Similar to tea growers, tea wholesalers from Uji Area also have a long line of family generations in this occupation and, in their case, tea blending techniques are the inherited knowledge which are passed down through generations. In order to produce high quality tea products, the tea wholesalers rely on tea leaves purchased from Uji Area and, under the current definition, it is possible for them to produce tea products using a mixture of tea leaves purchased from outside Uji Area with small amount of tea leaves from Uji Area, and still market them as Uji Tea.

Currently the Uji Tea trademark is registered under Ujicha Cooperative (京都府茶協同組合) which is an association of tea wholesalers in Kyoto Prefecture, where most of its members are based in Uji Area. From this information it can be concluded that Uji Tea brand is a trademark for tea products which are produced by tea wholesaler in Uji Area, and does not necessarily have to contain 100 percent tea leaves which are cultivated in Uji Area. In this definition it is also clear that the tea wholesalers retain the privilege to set the market price as well as control the market for Uji Tea itself.

Under the current definition, natural environmental elements and agriculture practices elements, which are important for determining the quality of the tea leaf, cover an area that is way beyond where the blending wholesaler is located in Uji Area. Thus, the product emphasis is placed more on the type of tea blends marketed by the tea wholesaler, where the sensory characteristics of the tea product (taste, aroma and color) are created through tea blending, rather than by controlling the cultivation of the tea leaf, especially when it is in the four prefectures outside Uji Area. This research is trying to highlight the importance of tea cultivation process as a trademark basis, similar to with the geographical indication applied in winegrape terroirs, such as the *appellation* characterizing winegrowing regions in France.

Based on the terroir concept, the tea products from Uji Area should possess unique characteristics which could only emerge through the combination of natural environmental elements in the tea plantations with the unique traditional tea cultivation practices in Uji Area. Thus, as indicated through this study, using these terroir elements (Natural Environmental Elements and Agriculture Practices Elements) as a basis for evaluating tea leaf quality would ensure that even when produced in regions outside Uji Area, one could see how close they could be brought to teas grown in the Uji Area, or how their particular characteristics could complement those of Uji's home grown teas to create marketable tea products under the Uji Tea brand.

Utilizing the values from bio-climatic indicators' calculation, analysis could be conducted to classify and categorize the tea products cultivated in the tea plantations inside Uji Area. From this analysis, the range and limitations of the tea products could be quantified across Uji Area. These values could also be utilized to redefine the terroir boundaries of Uji Tea, while justifying the usage of the Uji Tea trademark for tea products cultivated outside of Uji Area, as long as the relevant bio-climatic indicator values fall within the requirements standard of tea products from Uji Area.

The methodologies developed in this study could be used to develop more rigorous evidence-based quality assurance standards for tea leaf suppliers who wish to sell to Uji wholesalers. This may lead to a rational redefinition of the sources of tea lead supply for Uji teas, going beyond the four neighboring prefectures indicated earlier by providing a “functional indication”, rather than the “geographical indication” currently used. Although it might appear dramatically radical at present, such breakthrough might enable Uji tea leaf supply to go beyond Japan’s own boundaries without fears of quality deterioration. In the age of globalized trade, characterized by international agreements such as the Trans-Pacific Partnership (TPP), local producers in Uji might build on this rationale to get high quality leaf supply at globally competitive price from overseas, thereby retaining or enhancing the profitability of their operations.

The foundation laid in this research would lead the way to further research on understanding the relation between the terroir elements and its calculated bio-climatic indicator values with the quality of tea production characteristic such as taste, aroma and color. As showed in this research, through reformulation and recalculation of the bio-climatic indicators, the calculated values are proven to be important to understand the phenological response of a plant, irrespective of whether it is a fruit based crop, such as winegrape or a leaf based crop, such as tea. As it is already utilized in winegrape cultivation, further application on leaf based crops would be important to verify the relationship between the calculated bio-climatic indicator values and harvest quantity/quality. It is also hoped that the terroir based approach constructed from this research would be utilized in other agricultural crops, to define the relation between agricultural products and their terroir elements (Natural Environment Elements and

Agriculture Practices Elements), especially in regard to the application of bio-climatic indicators to swiftly adapt to meet rapid climatic and market changes while maintaining the quantity and quality of the crop production.

In conclusion, the limitations of this study must be mentioned since they will be the springboard for future work in this field. The terroir elements in the Natural Environment category used in this study are heavily biased towards the impact of climate centered indicators on the phenology of the tea plant, in particular on the tea leaf harvest yield. Soil-related analysis is minimal, with no quantitative analysis of soil quality changes brought about by climate change, as well as soil-related interventions by growers. This is because most growers contacted in Uji Area did not wish to share soil related information as they felt it to be proprietary knowledge which, if released to rival producers, would lead to loss of their competitive edge. Nevertheless, it is important to add such analyses to the work initiated in this study to further enhance the usefulness of bio-climatic indicators.

Detailed analysis on cultivars suited to different bio-climatic regimes also need to be strengthened. This could be a major benefit to new entrants selecting suitable sites and to current producers who wish to expand or move their production site. The impact of topography and aspect also need further analysis. Indeed, there is much work to be done. However, it is hoped that the seminal work conducted in this study will inspire succeeding generations of researchers to see how a hitherto qualitative concept like the terroir can be enriched through quantitative methodologies to serve an agricultural production region to sustain its activities and seek new ways of adding value to its products. The figure 6.2 shown below sums up the findings of this work, its policy implications and the next steps that future research in this area would have to take.

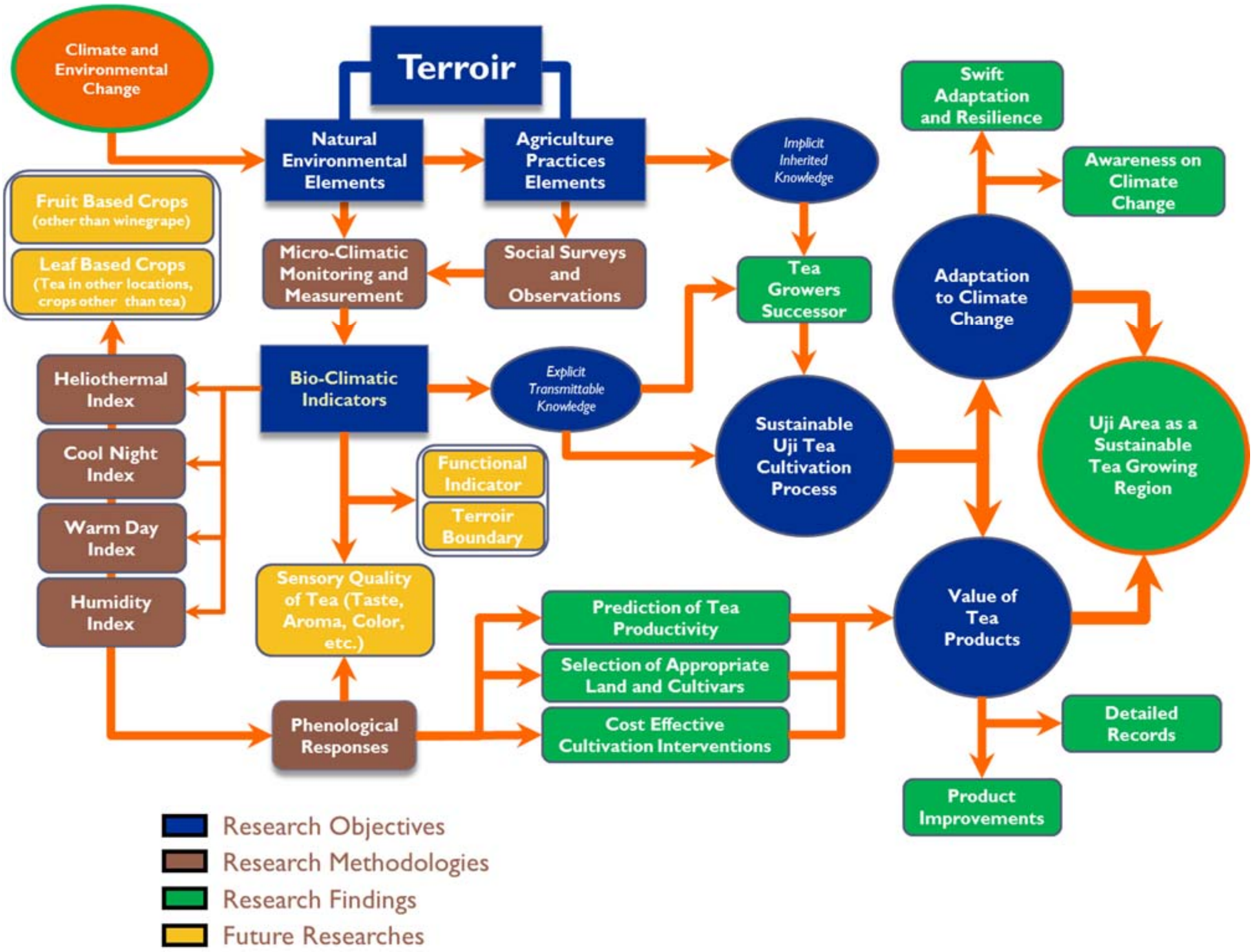


Figure 6.2 Summary of Research Findings, Policy Implications and Future Researches

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APPENDIX - A

Semi-Structured Questionnaire

【今日における宇治の茶農家の茶栽培の形態と実践について】

（このアンケートは、気候変動が茶栽培に与えている影響について、茶農家の皆さまのご経験を伺うためのものです。このアンケートの結果はプライバシー管理を徹底した上で、質問者の論文の執筆に利用させて頂きます。
このアンケート結果や分析についてのお問い合わせは質問者までお寄せください。気候変動が茶栽培に与える悪影響を未然に防ぎ、茶の品質向上につなげることに役立てます。皆さまのご協力をお願いいたします。）

１． あなたはどの年齢群に属しますか。（~19）（20~29）（30~39）（40~49）（50~59）（60~69）（70~）

２． あなたが茶栽培を行っている場所はどこですか。地図の上に示してください。

３． あなたの家系が最初に茶栽培を始めたのはいつですか。またあなた自身がそれに加わったのはいつですか。

４． あなたは茶栽培方法について誰から学びましたか。
（例： 家族、独学、教育機関 等）

５．　あなたが茶栽培において重要だと思う知識について順位づけをして、その理由を教えてください。

1. 家族から得た知識
2. 自分の経験に基づく知識
3. 教育機関から得た知識

６．　あなたは自分の作業記録をつけていますか。（つけている場合はどのような形で記録していますか？つけていない場合は今後つける予定はありますか？）

７．　あたなが働いている茶畑の所有者は誰ですか？

８．　茶畑の気候、土壌、地形の状況についてどのような方法で理解しましたか？

９．　あなたの畑の土壌のタイプを教えてください。

１０．現在あなたの畑で栽培している茶の品種はなんですか。それはこの２０年の間に変えたものですか。変えた場合はなぜその品種に変えたか教えてください。

１１．気候変動はあなたの栽培する茶の品質にこの２０年の間影響を与えていると思いますか。とりわけ土壌、地形、品種の変化の面から教えてください。

１２．あなたが茶栽培で実践している年間栽培法について説明してください。
（解答用紙をご利用ください）

１３．気候変動はあなたの茶栽培の方法にこの 20 年間で影響与えますか。与えている場合、具体的にどのような影響か教えてください。

１４．あなたは気象に関する情報をどのように得ていますか。
〔計測器を用いて／用いず自分で観察〕〔外部から入手〕
あなたは茶栽培を行う上で、どのように得た情報をもっとも信頼していますか。

１５．あなたには茶栽培において精密農業に用いる道具や方法を取り入れていますか。

１６．個人農家が精密農業の道具や方法を取り入れることは、茶栽培の改良に役立つと思いますか。あなたのご意見を教えてください。

１７．あなたの茶畑から収穫した茶の葉はどんな商品になりますか。
それはこの２０年の間に変わりましたか。変えた場合、その理由を教えてください。

１８．あなたは茶栽培のみによって、家計を維持することが可能ですか。その状況はこの２０年の間に変わりましたか。

１９．あなたは茶栽培が地域の環境に影響を与えていると思いますか。あるいは、地域の環境が茶栽培に影響を与えていると思いますか。

２０．茶栽培に関してあなたが現在の直面している問題は何ですか。（例：近隣住宅の増加、後継者問題、農業必要経費の値上がり、茶商品の値下げ）これらの問題にあなたはどのように取り組んでいますか。

２１．あなたは今日の茶栽培において重要な問題は何だと思いますか。あなたのご意見をお聞かせ下さい。

ご協力ありがとうございました。

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APPENDIX – B

Kyoto Prefecture Tea Industry Research – 2002

	Value	1a	1b	1c	2a	2b	2c	3a	3b	3c	4a	4b	4c	5a
AVG Mean (°C)		3.90	1.30	3.70	4.00	3.60	5.60	5.10	6.80	10.30	12.40	14.70	13.10	17.80
AVG Min (°C)		0.00	−2.90	−0.30	−0.40	−1.80	−0.30	0.20	0.10	4.30	4.60	7.60	6.40	12.40
AVG Max (°C)		7.90	5.40	7.70	8.40	9.00	11.60	9.90	13.60	16.20	20.30	21.90	19.80	23.20
Precipitation (mm)		47.60	15.30	69.30	37.00	1.00	44.20	45.30	12.40	29.00	2.50	21.70	23.90	36.50
Humidity (%)		70.50	61.20	78.70	76.40	67.70	72.60	69.10	67.30	67.90	66.00	63.00	67.10	76.00
Bud Break														
Fertilizer														
Leaf Covering														
Harvest														
HI	23.65				−3.80	−3.70	−1.40	−2.50	0.20	3.25	6.35	8.30	6.45	10.50
CI	3.00	−1.00	2.30	0.20	−0.50	−1.20	2.60	0.70	3.10	3.30	7.00	7.8	11.7	
Hum-I	69.31				76.40	67.70	72.60	69.10	67.30	67.90	66.00	63.00	67.10	76.00
WI	16.95							9.90	13.60	16.20	20.30	21.90	19.80	

Tea Productivity (Kg/Ha)	740.16
Tencha Production (Kg/Ha)	540.84
Gyokuro Production (Kg/Ha)	116.06
Tea Value (Yen)	718,005,000.00
Tencha Value (Yen)	619,269,000.00
Gyokuro Value (Yen)	79,164,000.00

Kyoto Prefecture Tea Industry Research - 2003

	Value	1a	1b	1c	2a	2b	2c	3a	3b	3c	4a	4b	4c	5a
AVG Mean (°C)		3.50	7.10	4.30	5.00	3.60	8.30	6.70	10.70	10.00	14.20	14.60	17.00	18.80
AVG Min (°C)		-1.00	2.30	0.20	-0.50	-1.20	2.60	0.70	3.10	3.30	7.00	7.80	11.70	14.10
AVG Max (°C)		8.00	12.00	8.20	10.40	8.30	13.70	12.80	18.30	16.90	21.40	21.40	22.30	23.50
Precipitation (mm)		29.00	5.70	74.00	15.00	34.40	22.90	72.90	21.50	37.20	56.30	25.20	88.60	64.50
Humidity (%)		68.50	76.60	69.20	76.10	72.10	72.00	69.40	65.10	71.30	66.00	71.10	72.00	77.10
Bud Break														
Fertilizer														
Leaf Covering														
Harvest														
HI	38.95				-2.30	-4.05	1.00	-0.25	4.50	3.45	7.80	8.00	9.65	11.15
CI	3.00	-1.00	2.30	0.20	-0.50	-1.20	2.60	0.70	3.10	3.30	7.00	7.80	11.70	
Hum-I	71.22				76.10	72.10	72.00	69.40	65.10	71.30	66.00	71.10	72.00	77.10
WI	18.85							12.80	18.30	16.90	21.40	21.40	22.30	

Tea Productivity (Kg/Ha)	826.00
Tencha Production (Kg/Ha)	586.24
Gyokuro Production (Kg/Ha)	139.22
Tea Value (Yen)	650,279,000.00
Tencha Value (Yen)	543,096,000.00
Gyokuro Value (Yen)	85,984,000.00

Kyoto Prefecture Tea Industry Research - 2004

	Value	1a	1b	1c	2a	2b	2c	3a	3b	3c	4a	4b	4c	5a
AVG Mean (°C)		5.10	4.00	2.70	3.80	5.60	8.10	5.30	9.40	10.30	11.90	17.50	15.20	18.70
AVG Min (°C)		0.40	0.70	-1.80	-1.00	-0.80	2.30	0.00	2.10	4.60	3.80	10.60	7.60	13.00
AVG Max (°C)		11.60	8.10	8.20	9.60	14.00	14.90	11.00	17.20	16.40	19.70	25.00	23.20	25.30
Precipitation (mm)		0.60	23.30	0.60	9.10	4.00	51.70	4.60	24.20	78.60	40.50	58.60	19.10	76.70
Humidity (%)		82.40	81.90	72.90	72.30	76.40	79.60	75.20	74.70	78.10	73.30	74.50	69.80	78.80
Bud Break														
Fertilizer														
Leaf Covering														
Harvest														
HI	41.05				-3.30	-0.20	1.50	-1.85	3.30	3.35	5.80	11.25	9.20	12.00
CI	2.38	0.40	0.70	-1.80	-1.00	-0.80	2.30	0.00	2.10	4.60	3.80	10.60	7.60	
Hum-I	75.27				72.30	76.40	79.60	75.20	74.70	78.10	73.30	74.50	69.80	78.80
WI	18.75							11.00	17.20	16.40	19.70	25.00	23.20	

Tea Productivity (Kg/Ha)	779.88
Tencha Production (Kg/Ha)	553.43
Gyokuro Production (Kg/Ha)	132.25
Tea Value (Yen)	612,382,000.00
Tencha Value (Yen)	511,368,000.00
Gyokuro Value (Yen)	81,464,000.00

Kyoto Prefecture Tea Industry Research - 2005

	Value	1a	1b	1c	2a	2b	2c	3a	3b	3c	4a	4b	4c	5a
AVG Mean (°C)		3.70	4.10	4.20	4.30	5.40	3.50	6.20	6.70	8.70	13.00	14.10	17.30	18.10
AVG Min (°C)		-0.40	0.60	-0.40	0.70	1.30	-1.40	0.70	1.10	2.90	5.00	7.60	9.30	11.80
AVG Max (°C)		8.60	8.90	9.40	8.60	9.40	9.50	13.00	12.40	14.20	20.90	21.10	25.40	24.80
Precipitation (mm)		13.10	27.10	2.40	17.10	46.60	6.90	14.00	39.90	44.40	2.60	34.70	2.60	64.30
Humidity (%)		76.40	73.50	72.00	70.90	75.90	69.30	71.30	73.90	72.10	65.80	67.00	61.70	69.80
Bud Break														
Fertilizer														
Leaf Covering														
Harvest														
HI	41.05				-3.30	-0.20	1.50	-1.85	3.30	3.35	5.80	11.25	9.20	12.00
CI	2.25	-0.40	0.60	-0.40	0.70	1.30	-1.40	0.70	1.10	2.90	5.00	7.60	9.30	
Hum-I	69.77				70.90	75.90	69.30	71.30	73.90	72.10	65.80	67.00	61.70	69.80
WI	17.83							13.00	12.40	14.20	20.90	21.10	25.40	

Tea Productivity (Kg/Ha)	755.25
Tencha Production (Kg/Ha)	533.98
Gyokuro Production (Kg/Ha)	128.85
Tea Value (Yen)	626,067,000.00
Tencha Value (Yen)	521,592,000.00
Gyokuro Value (Yen)	83,904,000.00

Kyoto Prefecture Tea Industry Research - 2006

	Value	1a	1b	1c	2a	2b	2c	3a	3b	3c	4a	4b	4c	5a
AVG Mean (°C)		2.50	4.90	3.20	3.20	5.60	6.90	6.70	6.20	7.50	10.60	13.00	13.20	18.80
AVG Min (°C)		-1.50	0.70	-0.90	-0.60	0.90	1.50	1.70	1.00	1.90	4.70	8.90	7.40	13.00
AVG Max (°C)		7.60	9.90	8.20	7.90	10.70	11.90	12.50	11.20	14.40	16.40	17.70	19.40	25.20
Precipitation (mm)		1.00	36.80	5.10	40.50	40.20	34.80	48.70	51.00	32.00	65.20	64.40	2.60	55.10
Humidity (%)		71.90	75.10	75.00	73.80	75.80	76.00	76.90	74.10	70.50	69.60	73.60	68.10	73.80
Bud Break														
Fertilizer														
Leaf Covering														
Harvest														
HI	19.50				-4.45	-1.85	-0.60	-0.40	-1.30	0.95	3.50	5.35	6.30	12.00
CI	2.14	-1.50	0.70	-0.90	-0.60	0.90	1.50	1.70	1.00	1.90	4.70	8.90	7.40	
Hum-I	73.22				73.80	75.80	76.00	76.90	74.10	70.50	69.60	73.60	68.10	73.80
WI	15.27							12.50	11.20	14.40	16.40	17.70	19.40	

Tea Productivity (Kg/Ha)	688.42
Tencha Production (Kg/Ha)	486.76
Gyokuro Production (Kg/Ha)	115.27
Tea Value (Yen)	567,294,000.00
Tencha Value (Yen)	473,712,000.00
Gyokuro Value (Yen)	74,784,000.00

Kyoto Prefecture Tea Industry Research - 2007

	Value	1a	1b	1c	2a	2b	2c	3a	3b	3c	4a	4b	4c	5a
AVG Mean (°C)		4.90	4.60	4.90	6.00	6.20	7.40	8.00	4.60	10.30	10.40	13.10	16.00	18.50
AVG Min (°C)		0.90	-0.30	-0.40	0.10	0.60	0.80	1.50	-0.50	3.20	4.30	6.60	8.80	12.50
AVG Max (°C)		10.10	10.60	11.20	11.80	12.00	14.10	15.30	10.20	17.60	16.80	20.60	23.30	25.00
Precipitation (mm)		11.80	11.00	0.30	8.10	43.60	23.40	11.20	13.30	44.10	9.80	27.40	13.20	53.30
Humidity (%)		78.30	78.50	74.00	71.70	73.20	71.30	68.70	68.30	75.30	70.10	67.40	70.60	75.30
Bud Break														
Fertilizer														
Leaf Covering														
Harvest														
HI	33.60				-1.10	-0.90	0.75	1.65	-2.60	3.95	3.60	6.85	9.65	11.75
CI	2.13	0.90	-0.30	-0.40	0.10	0.60	0.80	1.50	-0.50	3.20	4.30	6.60	8.80	
Hum-I	71.19				71.70	73.20	71.30	68.70	68.30	75.30	70.10	67.40	70.60	75.30
WI	17.30							15.30	10.20	17.60	16.80	20.60	23.30	

Tea Productivity (Kg/Ha)	765.19
Tencha Production (Kg/Ha)	545.60
Gyokuro Production (Kg/Ha)	126.38
Tea Value (Yen)	630,988,000.00
Tencha Value (Yen)	528,531,000.00
Gyokuro Value (Yen)	81,796,000.00

Kyoto Prefecture Tea Industry Research - 2008

	Value	1a	1b	1c	2a	2b	2c	3a	3b	3c	4a	4b	4c	5a
AVG Mean (°C)		5.30	4.00	3.80	2.90	3.40	4.10	5.90	11.50	10.70	12.00	14.50	16.40	19.10
AVG Min (°C)		0.50	0.30	0.70	-0.60	-0.80	-0.90	0.40	5.40	4.40	5.60	9.80	8.90	12.30
AVG Max (°C)		11.70	8.90	6.90	7.60	8.80	10.40	12.40	18.20	17.40	18.80	20.10	24.70	26.40
Precipitation (mm)		1.30	22.60	29.50	33.70	7.70	33.50	16.70	59.40	39.90	76.40	73.80	15.00	26.30
Humidity (%)		77.40	78.10	81.50	82.10	75.10	74.40	75.40	73.70	73.20	72.40	78.20	71.20	70.10
Bud Break														
Fertilizer														
Leaf Covering														
Harvest														
HI	32.65				-4.75	-3.90	-2.75	-0.85	4.85	4.05	5.40	7.30	10.55	12.75
CI	2.81	0.50	0.30	0.70	-0.60	-0.80	-0.90	0.40	5.40	4.40	5.60	9.80	8.90	
Hum-I	74.58				82.10	75.10	74.40	75.40	73.70	73.20	72.40	78.20	71.20	70.10
WI	18.60							12.40	18.20	17.40	18.80	20.10	24.70	

Tea Productivity (Kg/Ha)	764.97
Tencha Production (Kg/Ha)	543.72
Gyokuro Production (Kg/Ha)	127.30
Tea Value (Yen)	623,231,000.00
Tencha Value (Yen)	521,311,000.00
Gyokuro Value (Yen)	81,365,000.00

Kyoto Prefecture Tea Industry Research - 2009

	Value	1a	1b	1c	2a	2b	2c	3a	3b	3c	4a	4b	4c	5a
AVG Mean (°C)		5.00	3.60	5.90	5.10	7.10	7.50	7.90	9.70	8.30	11.00	17.50	14.10	18.10
AVG Min (°C)		1.40	-0.80	1.10	-0.40	1.50	3.30	3.10	2.80	2.30	3.60	10.30	7.20	12.50
AVG Max (°C)		10.00	9.10	10.90	11.40	12.70	11.90	13.20	16.90	15.70	20.00	25.50	20.80	24.70
Precipitation (mm)		10.30	14.70	70.80	13.40	53.60	55.30	39.50	73.80	23.20	20.20	35.40	55.70	43.00
Humidity (%)		80.40	76.20	79.00	76.40	77.40	79.90	75.70	74.90	69.10	69.20	67.70	70.10	67.50
Bud Break														
Fertilizer														
Leaf Covering														
Harvest														
HI	39.55				-1.75	-0.10	-0.30	0.55	3.30	2.00	5.50	11.50	7.45	11.40
CI	2.95	1.40	-0.80	1.10	-0.40	1.50	3.30	3.10	2.80	2.30	3.60	10.30	7.20	
Hum-I	72.79				76.40	77.40	79.90	75.70	74.90	69.10	69.20	67.70	70.10	67.50
WI	18.68							13.20	16.90	15.70	20.00	25.50	20.80	

Tea Productivity (Kg/Ha)	821.91
Tencha Production (Kg/Ha)	530.15
Gyokuro Production (Kg/Ha)	173.64
Tea Value (Yen)	632,520,000.00
Tencha Value (Yen)	497,718,000.00
Gyokuro Value (Yen)	109,184,000.00

Kyoto Prefecture Tea Industry Research - 2010

	Value	1a	1b	1c	2a	2b	2c	3a	3b	3c	4a	4b	4c	5a
AVG Mean (°C)		4.40	3.70	4.90	5.00	4.60	11.40	8.80	9.90	7.40	12.60	13.00	13.10	18.80
AVG Min (°C)		0.50	-1.10	0.40	0.80	0.40	6.50	5.70	3.30	2.90	5.80	8.80	7.70	11.10
AVG Max (°C)		9.30	10.10	10.30	10.40	9.60	17.30	12.40	17.10	12.80	19.70	17.70	18.90	26.80
Precipitation (mm)		5.50	3.30	29.80	35.60	45.30	70.20	39.70	51.90	72.10	87.40	60.40	121.20	22.00
Humidity (%)		71.80	74.60	82.80	79.10	79.60	82.00	88.20	75.00	77.80	71.80	78.20	71.30	69.90
Bud Break														
Fertilizer														
Leaf Covering														
Harvest														
HI	33.65				-2.30	-2.90	4.35	0.60	3.50	0.10	6.15	5.35	6.00	12.80
CI	3.48	0.50	-1.10	0.40	0.80	0.40	6.50	5.70	3.30	2.90	5.80	8.80	7.70	
Hum-I	77.29				79.10	79.60	82.00	88.20	75.00	77.80	71.80	78.20	71.30	69.90
WI	16.43							12.40	17.10	12.80	19.70	17.70	18.90	

Tea Productivity (Kg/Ha)	813.24
Tencha Production (Kg/Ha)	522.53
Gyokuro Production (Kg/Ha)	174.30
Tea Value (Yen)	631,988,000.00
Tencha Value (Yen)	496,620,000.00
Gyokuro Value (Yen)	109,880,000.00

Shichimei-en – 2014

	Value	1a	1b	1c	2a	2b	2c	3a	3b	3c	4a	4b	4c	5a
AVG Mean (°C)		3.90	2.27	4.42	4.00	5.13	8.99	5.51	10.85	11.53	11.79	13.56	15.62	17.35
AVG Min (°C)		−0.32	−2.34	−0.75	1.63	−0.52	2.04	−0.11	4.26	6.11	5.47	6.41	10.26	10.28
AVG Max (°C)		8.98	7.83	8.35	7.1	7.58	13.08	9.21	15.40	17.25	19.31	20.70	23.05	25.46
Precipitation (mm)		30.69	1.75	15.56	4.40	23.00	0.00	18.40	42.00	62.60	10.80	7.20	33.20	1.40
Humidity (%)		82.44	80.16	81.90	77.49	70.38	73.11	78.41	67.32	69.03	63.97	54.61	66.88	60.65
Bud Break														
Fertilizer														
Leaf Covering														
Harvest														
HI	30.92				−4.29	−3.74	1.28	−2.90	2.60	4.30	5.63	7.01	9.57	11.46
CI	2.68	−0.32	−2.34	−0.75	1.63	−0.52	2.04	−0.11	4.26	6.11	5.47	6.41	10.26	
Hum-I	68.19				77.49	70.38	73.11	78.41	67.32	69.03	63.97	54.61	66.88	60.65
WI	17.49							9.21	15.40	17.25	19.31	20.70	23.05	

Koyama-en - 2014

	Value	1a	1b	1c	2a	2b	2c	3a	3b	3c	4a	4b	4c	5a
AVG Mean (°C)		4.54	2.98	5.28	4.77	3.27	6.47	5.60	8.79	11.60	12.00	13.45	16.25	17.52
AVG Min (°C)		0.47	-1.47	0.10	1.22	-0.25	1.60	1.22	2.92	5.86	5.07	5.96	10.11	10.50
AVG Max (°C)		9.25	8.05	10.60	9.16	7.40	12.14	9.72	14.52	17.11	19.67	20.88	23.43	25.46
Precipitation (mm)		33.38	3.00	19.12	21.54	28.00	8.53	18.00	42.70	68.80	12.78	8.82	30.88	0.25
Humidity (%)		77.78	74.92	77.10	78.75	73.25	72.11	74.37	73.20	71.56	67.42	57.02	68.32	62.46
Bud Break														
Fertilizer														
Leaf Covering														
Harvest														
HI	29.56				-3.03	-4.66	-0.70	-2.34	1.65	4.31	5.84	7.16	9.84	11.49
CI	2.73	0.47	-1.47	0.10	1.22	-0.25	1.60	1.22	2.92	5.86	5.07	5.96	10.11	
Hum-I	69.85				78.75	73.25	72.11	74.37	73.20	71.56	67.42	57.02	68.32	62.46
WI	17.57							9.72	14.52	17.11	19.67	20.88	23.43	