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Climate Change Adaptation for Agro-Forestry Industries: Sustainability Challenges in Uji Tea Cultivation

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Abstract

The on-going changes in the climate conditions have been affecting the agriculture industries, where the effects are likely to be region specific. There is a need for different types and levels of adaptation in each region based on its conditions and resources. This study focuses on theUji area of Kyoto, which is one of the oldest and most famous producers of green tea in Japan. Recent changes have been slowly affecting the quality of the tea produced in the region, as well as further decliningofthe tea quantity cultivated in Uji area. In order to sustain the area as a vibrant tea producer, specific and localized adaptation methods need to be developed. The development of *terroir*(as used in winegrape producing regions) derived bio-climatic indicators linked withtraditional agriculture knowledgein long-standing tea farmer communities, is very important in developingprecision agriculture systemfor adapting to climate change. Indicators such as Heliothermal Index, THSW Index, Cool Night Index, Dryness Index, as well as Soil Respiration Index can be retranslated into indicators for evaluating optimal conditions for growing quality teas. Selection of the most appropriate land, cultivars and cultivation methods for quality tea production can be applied and conducted as these indicators are likely to become a powerful tool for monitoring the impacts of climate change and adapting pro-actively to the environmental transformation, while maintaining and enhancing the values of the teas produced.The development of bio-climatic indicators will not only be useful for Uji area, but also in other tea growing regions in the world.

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Keywords: Climate Change; Tea Cultivation; *Terroir*; Traditional Agriculture Knowledge; Precision Agriculture System; Bio-Climatic Indicators

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1. Climate Change and Tea Cultivation

With regards tothe rapidly transforming climate conditions,the agriculture and forestry industriesare among those, which are directly affected. Agricultural crops are grown and harvested seasonally in a specific period of climatic condition to obtain the optimumof desired harvest quantity and quality. Some of the crops require certain temperature ranges as well as certain intensity of solar radiation, which directly affectharvest quality and yield. In these industries, tea and winegrape cultivation are among those, which are very sensitive towards changes in the climatic condition whereas changes in the climatic region will directly affect the quality of the cultivated products. Based on Intergovernmental Panel on Climate Change (IPCC) [1], climate change is expected to manifest itself in the increasesof mean temperature, altered precipitation patterns, greater frequency of extremes, and increased climatic variability.

Although winegrapes as well as crops are not very crucial to human survival, the extraordinary sensitivity of the vine towards climate makes the industry a strong early-warning system for problems that all food crops may confront as climates continue to change [2]. This is also true for the tea industry, as changes in the climate occurring in the surrounding area of tea bushes directly influence the quality of the picked leaves during harvest. Similarly with winegrape cultivation, tea is sensitive to climate changes with potential effects on its yield, quality and economic viability as it is directly connected with the market.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.

1.1. Average Temperature Increase

Climate condition data from long-term observation showed that in general average temperature is increasing in many parts of the world. The increase of average temperature might be beneficial for agriculture production as colder climate region become warmer; cultivation of crops that were impossible to grow before becomes feasible. On the contrary, currently well-known growing regions might not be suitable for cultivation in the future anymore, as the average temperature is getting too high. This condition might trigger a shift in suitable locations for some varieties cultivation in order to obtain high quality harvest [3]. The influence of higher temperature to the tea cultivation might not be as devastating as winegrape cultivation but never the less, higher temperature regimes reduces tea yield [4]. In the case of Japan, meteorogical data clearly showed that for 120 years period from 1891 to 2011 the average temperature trend is increasing by 1.15oC/100 Years [5].

1.2. Increasing Occurrences of Extreme Weather Events

In parallel with the increase of average temperature, occurrences of extreme weather events have been increasing, whether it is days with abnormal temperature, changing pattern of rainfall or disastrous events such as hurricane and cyclones. The most affecting climate events for the tea cultivation are related tomean air temperature and precipitation of the macro and micro climatic conditions. Mean air temperature conditions contribute significantly towards tea plants, especially during the spring and fall season, as temperature is the determinant factor for the plants to be active after dormant or to enter dormant period. In fact, for the tea cultivation cycle on thetemperate climate regions, bud break process is one of the most important stages in cultivation, which is determined by mean air temperature condition. The seasonal changes from winter to spring and its gradual increase of mean air temperature become the natural signaling mechanism for the plants to end their dormant period and enter bud break period.

Jones [6] noted an increasing frost damage in the spring for thewinegrape cultivation, whichis also happening for tea cultivation in the temperate region, as there are increasing trends of frost event. From these researches we can conclude that there isan increase in the occurrences of abnormal climate events especially in micro climatic scale. Frost event that happened during the spring is very detrimental towards tea plants, as the ground temperature suddenly drops below freezing point, freezing the water vapor on the surface of the tea leaves and creating irreversible damages as the leaf withered causing loss in harvest quantity. Although the increase of frost event occurrenceshas not been too significant, the sudden fluctuations in the mean air temperature have been increasing in the past years. Extreme fluctuations of mean air temperature especially those which are happening during the spring season, can damage newly sprouted leaf bud as well as affecting tea leaf growth which lead to a declining harvest quality.

2. Uji Tea Cultivation

Uji City is located in the south of Kyoto City with the population of 189,609 people, living in a land area of 67.55 km^2, and the most well-known green tea producing region in Japan. Tea cultivation in Uji Area has a long history as the first cultivation dates back to 1191 AD. The term "Uji-cha" or Uji Tea is very famous in Japan, although the definition of Uji Tea does not only confine to Uji area only. The definition of Uji Tea is tea that is cultivated inside four prefectures, which are Kyoto, Nara, Shiga and Mie, and processed into tea products within Kyoto Prefecture boundaries by tea producers from Kyoto Prefecture. Currently Uji Area have 81.6 Ha existing tea fields, whereas 80 Ha is mature tea field and 1.6 Ha is tea fields under development. There are eleven cultivars of tea which are generally cultivated by the tea farmers, which are: 1) Uji Midori; 2) Kyo Midori; 3) Yabukita; 4) Samidori; 5) Asahi; 6) UjiHikari; 7) Ogura Midori; 8) Gokou; 9) Komakage; 10) Oku Midori; and 11) Sae Midori. From these cultivars the most high quality tea products are *gyokuro* and *tencha* (*matcha*), which generally produced from Samidori and Asahi cultivars.

In general the tea farmers in Uji area are using three types of bush management, which are the flat bush, arch bush and natural bush. The differences among these bushes are based on methods of harvesting, whereas flat and arch bushes utilized mechanical harvest while only the natural bush is manually hand plucked by the tea farmers.Apart from the plant management,Ujitea cultivation is famous for the tea growing technique, which is the covering method. Tea bushes are covered with sunlight blocking materials at the moment of first bud break, whereas the light intensity is reduced by 95 percent for the first 2-3 weeks and further to 98 percent during the last week prior to harvesting.The covering method is used to create a condition where the tea bushes would grow in deprived sunlight throughartificial methodssuch as using black vinyl sheet or a more traditional way by using woven reed branch and straws. With reduced intensity of direct sunlight, it creates a condition that force the tea plant to produce more chlorophyll in the leaves, which is the desired effect of this cultivation method. Increased chlorophyll and amino acids amount in the leaf is believe to give more taste and sweetness to the tea.

a

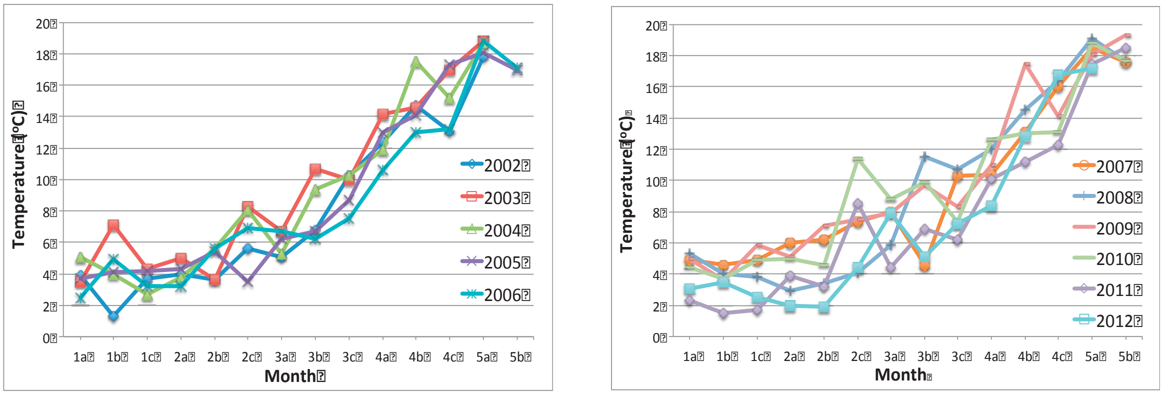

Fig. 1. (a) Recorded Average Temperature (oC) between January to May (2002-2006); (b) Recorded Average Temperature (oC) between January to May (2007-2012), [7].

2.1. Climatic Conditions in Uji Area

Based on data from Kyoto Prefecture Tea Industry Research [7], temperature data has shown that in the last 10 years mean air temperature fluctuation in micro climatic scale has becoming more apparent, especially during the period of seasonal changes. As shown in Fig.1., recordedaverage air temperature data between January to May, it is clearly shown that the fluctuations in gradual change of mean air temperature between seasons have become steeper.

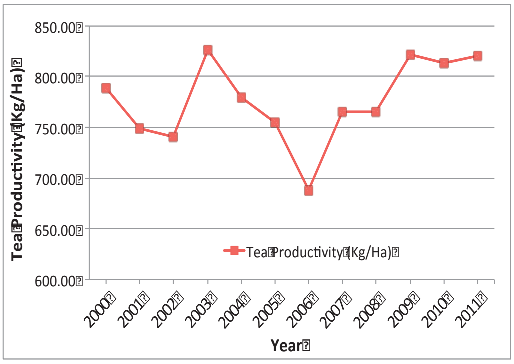

Fig. 2.Uji Tea Productivity(2000 – 2011), [7].

The fluctuations of mean temperature are more apparent in the last six years (2007-2012) compared to the years before (2002-2006). Mean temperature data is dividedinto 10 days division in each month, whereas (a) represent the 1^{st} to 10^{th} day, (b) represent 11^{th} to 20^{th} day, and (c) represent 21^{st} day until end of the month.

From the same data source it is also apparent that the declines in tea yield (Fig.2) can be correlated with the climatic conditions especially the temperature fluctuations, which through regression analysis (Fig.3) it is shown that there is clear correlations between changes in the temperature with the tea productivities especially in the period of Beginning of March (3a) to Beginning of May (5a).

2.2. Seasonal Agricultural Practices

Data on seasonal tea cultivation practices were collected through social survey as well as observations of tea cultivation practices. Surveys and observations were conducted with the cooperation of ten tea famers in Uji Area. The social survey consist of semi-close ended questionnaires accompanied with direct interview, while the observations of seasonal tea cultivation practices were conducted through direct observations with cross referencing fromliterature data.

In general the tea cultivation process in Uji Area follows a single flow of cultivation process, whichis a complete season lasted for a full one year. Although there are some tea farmers who are able to harvest tea leavesfor 2 to 3 times a year, in general the tea farmers in Uji Area conduct harvestingonly once a year to maintain its quality.

Based on the analysis of the gathered data as shown in fig.4, approximately one month prior to bud break, tea farmers apply fertilizer on the dormant tea bushes. The most crucial period of tea cultivation process takes place between the beginning of March until the beginning of May. Pruningtakes place immediately after harvesting isfinished, with the degree of pruning depth depends on each farmers. The second treatment towards the soil is conducted around mid-summer season to allow optimal nourishment for the plant.In general dormant period will start around mid of November where the average temperature has drop below 10^{o}C.

Regression Statistics	
Multiple R	0.997197
R Square	0.994402
Adjusted R Square	0.955213
Standard Error	9.471329
Observations	9

Fig. 3.Regression analysis on tea productivity and average temperature in Ujiarea.

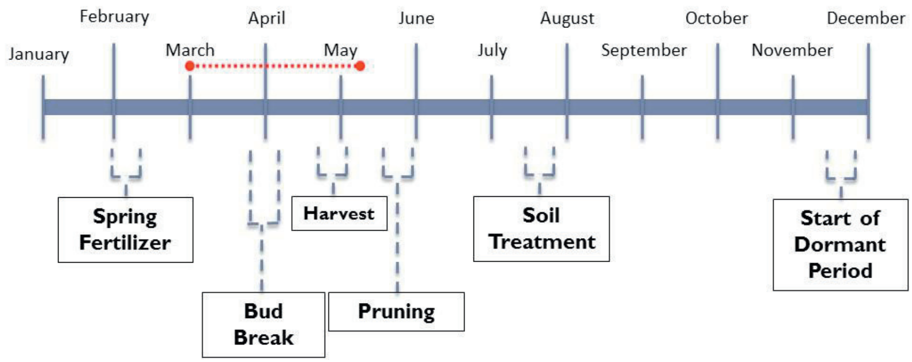

Fig. 4.Tea cultivation process in Ujiarea.

3. Bio-Climatic Indicators for Climate Change Adaptation

As Uji Area is the oldest and most famous green tea producing region in Japan, most of the tea farmersin the area have been cultivating tea for hundred years over several generations. As clearly seen in winegrape growing regions,the transfer of traditional agriculture knowledge among generation have ensured the continuity of the industry, therefore knowledge transfer of cultivation knowledge between generations of tea farmers in Uji Area become one of the focal point for this research. Accumulation of knowledge on seasonal agriculture practice and the understanding of local *terroir* condition are very important for tea farmers in order to produce tea products that are able to retain their family tradition. These understandings are very crucial to identify the changes that occurred in the region, especially the links between climatic conditions with tea production properties as past cultivation experiences and climatic conditions are also implicitly included in the knowledge.

In order to understand the intricate relationship between *terroir* and seasonal agricultural practices in traditional agriculture knowledge (TAK), and also to assess the impact of climate change towards these factors, a research framework for this research have been constructed.

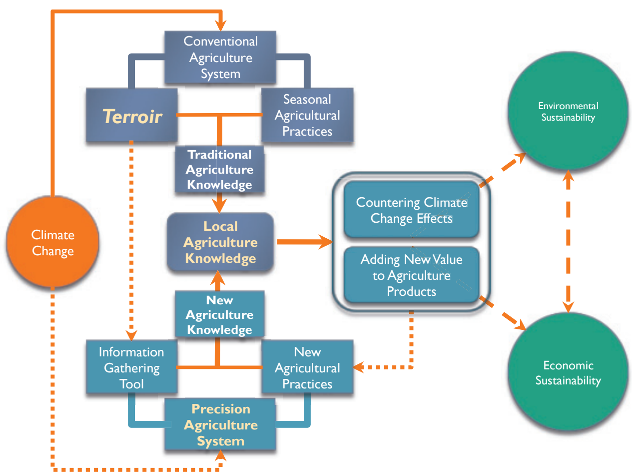

Fig. 5.Climate Change Adaptation Framework

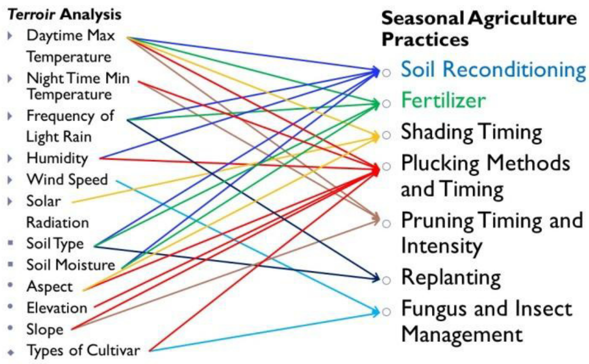

Fig. 6.Cross Referencing between Terroir factors and Traditional Agriculture Practices

3.1. Terroir and Traditional Agriculture Knowledge

In teacultivation climatic conditions of a certain area played very significant role not only to achieve favorable harvest yield and quality, but also contributes to the desired distinctive characteristicof the tea products. Derived from viticulture, the concept of *terroir* has been regarded as the most important factors in grape growing and wine making. Van Leeuwen and Seguin [8] explained that *terroir* concept describes the relationship between the characteristic of an agricultural products and its geographical origin, which influence these characteristics.In general term *terroir* concept consists of four main factors, which are: 1) Climate; 2) Soil; 3) Topography and 4) Cultivars.

Throughout generations of tea farmers, the characteristic of Uji Area *terroir*have been closely observed and incorporatedin the cultivation practices, thus gave birth to the special characteristic of Uji tea products. This knowledge then accumulates into traditional agriculture knowledge, which is passed down through generations of tea farmers. Knowledge on environment conditions is generally passed down through generations of farmers and it often includes information on past environmental conditions as it describes the methods to adapt with the conditions [9]. Traditional agriculture knowledge in this definition generally composed of: 1) Cultivation Method; 2) Soil Management Practices and 3) Socio-Economic Condition of an area or localities.

3.2. Process Analysis of Bio-Climatic Indicators

Through *terroir* observations and social survey conducted among Uji Area tea farmers on seasonal agriculture practices, several key factors in Ujitea cultivation can be clearlypointed out. Based on observations and survey data, Uji tea farmers have regarded these bio-climatic factors as very crucial in the seasonal agriculture practices of Uji tea cultivation. Thefactors are identified through extrapolation of climatic data with social survey result, whereas cross referencing the two factors clearly showed how temperature and soil factors are highly considered as the most crucial factors in the cultivation process of Uji Tea.

By utilizing bio-climatic indicators derived fromwinegrape cultivation, similarkey bio-climatic factors in Uji tea cultivation can be translated into several important bio-climatic indicators which correspondent with the two most crucial factors. The applicable bio-climatic indicators developed from the key bio-climatic factors would be: 1) Heliothermal Index; 2) THSW Index; 3) Dryness Index; 4) Cool Night Index; and 5) Soil Respiration.

3.3. Heliothermal Index

Originally Heliothermal Index (HI) is a viticultural climate index developed by Huglin [10], 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. HI is related to the thermal requirements of grape varieties and to potential sugar content of grapes.

In the case of tea cultivation heliothermal index can be utilized to identify suitable locations for tea growing, whereas temperature factor have significant impact towards the tea cultivation. This approach is important to identify suitable tea growing location, whereas topographic factors are directly affecting the microclimate condition of tea plantation inUji Area.

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

Fig. 7. Heliothermal Index (HI) [10]

T = Mean Air Temperature
Tx = Maximum Air Temperature
d = Length of day coefficient ranging from 1.02 to 1.06 between 40° and 50° of Latitude

Whereas:
$HI \leq 1500$ → Very Cool
$1500 < HI \leq 1800$ → Cool
$1800 < HI \leq 2100$ → Temperate
$2100 < HI \leq 2400$ → Temperate Warm
$2400 < HI \leq 3000$ → Warm
$3000 < HI$ → Very Warm

3.4. THSW Index

Developed by Steadman [11] to calculate apparent temperature (AT), using temperature-humidity relations which THSW incorporates the heating effects of solar radiation and the cooling effects of the wind.

$$AT = Ta + 0.348 \times e - 0.70 \times ws + 0.70 \times Q/(ws + 10) - 4.25$$

Ta = Temperature (°C)
e = Water vapour pressure (hPa) [humidity]
ws = Wind speed (m/s) at an elevation of 10 meters
Q = Net radiation absorbed per unit area of body surface (w/m^2)

3.5. Dryness Index

Dryness Index (DI) is a viticultural climate index that characterizes the water component of a region, strongly related to the qualitative characteristics of grapes and wine [10]. DI was adapted from the potential water balance of soil index. It takes into account the climatic demand of a standard vineyard, evaporation from bare soil, rainfall without deduction for surface runoff or drainage. It indicates the potential water availability in the soil, related to the level of dryness in a region. As in general both tea cultivation and winegrape cultivation only relies to natural precipitation only, this indicator will be very important for the cultivation process as this index measures soil water.

$$W(DI) = Wo + P - T_v - E_s$$

W	=	The estimate of soil water reserve at the end of given period
Wo	=	Initial useful soil water reserve
P	=	Precipitation
T_v	=	Potential transpiration
E_s	=	Direct evaporation from the soil

Whereas:

DI ≤ -100	→	Very Dry
-100 < DI ≤ 50	→	Moderately Dry
50 < DI ≤ 150	→	Sub Humid
150 < DI	→	Humid

3.6 Cool Night Index

Cool Night Index (CI) is a viticultural climate index developed to estimate the nictothermal condition associated with the grape maturation period [10]. Using minimum temperatures, the index serves as an indication of a region's potential characteristics with respect to secondary metabolites (polyphenols, aromas, color) in grapes and wines. This index evaluates the minimum night temperature of the month where important cultivation event occurs. In correlation with the tea cultivation, tea plant will enter inactivity period when temperature drops below 10°C.

CI for the Northern Hemisphere =mean *(T_{min}) for September in ºC*

Whereas:

CI ≤ 12	→	Very Cool Nights
12 < CI ≤ 14	→	Cool Nights
14 < CI ≤ 18	→	Temperate Nights
18 < CI	→	Warm Nights

3.7 Soil Respiration

Soil respiration is a measure of carbon dioxide (CO_2) released from the soil from decomposition of soil organic matter (SOM) by soil microbes and respiration from plant roots and soil fauna [12]. It is an important indicator of soil health because it indicates the level of microbial activity, SOM content and its decomposition.In the short term high soil respiration rates are not always better; it may indicate an unstable system and loss of soil organic matter (SOM) because of excessive tillage, or other factors degrading soil health.

$$R = R10\ x\ exp\left[308.56\left(\frac{1}{56.2} - \frac{1}{T-223.17}\right)\right] \quad (1)$$

R	=	Soil Respiration
$R10$	=	Soil Respiration at 10°C
T	=	Absolute Soil Temperature (K)

4. Conclusion and Further Discussion

Based on the analysis of gathered climatic data, it is seen that there is clear correlation between seasonal tea productivity with the average temperature, especially in the period of Beginning of March (3a) to Beginning of May (5a).Between this time periods there are several critical cultivation process that occurred such as bud break, leaf growth and harvesting. In this period the associated occurrences of climatic events includes sudden drop of temperature as well as frost event. Astea plants in general are actively growing at temperature above 10^{o}C, sudden drop in the temperature would be detrimental on growing leaf buds, moreover frost events which will permanently damage the leaf and reduces the harvest yield. Survey result has also indicated that, although the harvest yield was not significantly affected, extreme temperature fluctuations havecaused poor harvest quality caused by changes in the characteristic of harvested tea leaves.

Through process analysis of Uji Area tea *terroir* and inherited traditional agriculture knowledge of Uji Tea farmers, soil factor came as one of the two most important factors in Uji Tea cultivation. From these factors, critical bio-climatic indicatorsderived from winegrape cultivation such as Heliothermal Index, THSW Index, Cool Night Index, Dryness Index and Soil Respirationcan be retranslated into indicators for evaluating optimal conditions for growing quality teas. Selection of the most appropriate land, cultivars and cultivation methods for quality tea production can be applied and conducted as these indicators are likely to become a powerful tool for monitoring the impacts of climate change and adapting pro-actively to the environmental transformation, while maintaining and enhancing the values of the teas produced.

Further research especially on the application of the proposed bio-climatic indicators in Uji Area tea cultivation would be a necessary process to finetune the indicators into a practical solution in adapting climate change effect. The development of bio-climatic indicators will not only be useful for Uji area, but also in other tea growing regions in the world as it provide the basis for constructing framework on countering climate change effects. Not only applicable to the tea cultivation process, but this framework would also be utilizable in agriculture and forestry industry in general.

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