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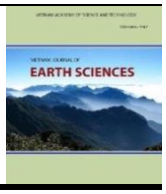

Bioclimatic assessments for tea cultivation in Western Nghe An

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ABSTRACT

Bioclimatology is applied for growing tea in the West of Nghe An province, where the tea is considered as a high economic efficient plant to be priorly cultivated for reducing poverty and getting rich. Based on the bioclimatic characteristics of tea plant and regional climatic data from 1980 to 2014, the bioclimatic diagrams are built and the tea cultivability is mapped in term of annual average temperature and total precipitation, for this region with regarding its district of Con Cuong as an analytical key. The climate, including both temperature and precipitation, in Con Cuong is relatively suitable for the tea plantation. The Western Nghe An, a land of approx. 1.4 million ha, could be classified in five areas with different suitability for tea plant. The unfavorable area occupies only 1% of the total region and the four favorable rests account for 99% of total, in which, the most favorable area is largest with about 746,355 ha, i.e. over 50% of whole region. The three other areas are cultivable but they are less favorable in terms of either temperature or precipitation. Growing tea in Western Nghe An, even in favorable areas, it should be taken into account of the weather disadvantages in certain moments of the year such as extremely dry, cold, hot and rainy events.

Keywords: Bioclimate; climate; tea; Western Nghe An.

1. Introduction

The West of Nghe An province is a mountainous region endowed with many advantages for development but its inhabitants largely still live in difficulties. The provincial authorities have many solutions to exploit the regional potentials for economic development and improvement of living standard of local people. In the master plan for socio-economic development of Nghe An, the agriculture is ecologically oriented with high technologies; its structure change, according to scientific and technical advances, in direction of raising added value; investments in agriculture and rural areas are encouraged; large-scale concentrated production areas are developed in association with processing and export industries and applying high technologies. In Nghe An Province, as a high economic plant with important role in reducing poverty, improving livelihoods for mountainous habitants, tea has been paid attention in provincial development planning, documented by Decision No. 448 /QĐ-UBND dated on January 31, 2013 and Decision No. 6290/QĐ-UBND dated on December 24, 2013. The tea zoning in these documents is based on the regional physical conditions, especially the relief and soil. However the here mentioned

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prior criteria for tea plantation such as large enough The West of Nghe An province is a mountainous region endowed with many advantages for development but its inhabitants largely still live in difficulties. The provincial authorities have many solutions to exploit the regional potentials for economic development and improvement of living standard of local people. In the master plan for socio-economic development of Nghe An, the agriculture is ecologically oriented with high technologies; its structure change, according to scientific and technical advances, in direction of raising added value; investments in agriculture and rural areas are encouraged; large-scale concentrated production areas are developed in association with the processing and export industries and applying high technologies. In Nghe An Province, as a high economic plant with an important role in reducing poverty, improving livelihoods for mountainous habitats, tea has been paid attention in provincial development planning, documented by Decision No. 448 /QĐ-UBND dated on January 31, 2013, and Decision No. 6290/QĐ-UBND dated on December 24, 2013. The tea zoning in these documents is based on the regional physical conditions, especially the relief and soil. However, the here mentioned prior criteria for tea plantation such as large enough areas, slope below 25°, arable thickness over 50 cm, conveniences in transportation and irrigation, all is general and can be applied to many different crops. The specific ecological requirements, including climatic conditions, especially the bioclimatic condition, for tea have not been paid attention.

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On the other hand, climate effects on tea have been studied for a long time in the world. The early studies focused on the impacts of climatic elements such as temperature, precipitation, and light condition on tea growth (Naykayma and Harada, 1962; Sen et al., 1966; Carr, 1972; Hardfield, 1976; Huang Soubo, 1989; Kabir, 2001). The later studies quantified the effects of climate are not only on the tea growth but also on economic aspects such as quality and yield (Kandiah and Thevadasan, 1980; Tanton, 1982; Carr and Stephen, 1992; Bhagat et al., 2010; Ducan et al., 2016). Recently, there have been many studies on the effects of climate change to tea industry (Wijeratne, 1996; Wijeratne et al., 2007; Ahmaed, 2014; Daleen and David, 2014; Kaye, 2014; Nkomwa et al., 2014; Schepp, 2014; Rebecca et al., 2016; International Center for Tropical Agriculture, 2017).

In Vietnam, the recent studies on climate and bioclimate are mainly for general crops, but some works of Nguyen Dai Khanh (2003) and Nguyen Bao Ve (2005) particularly focus on the tea plant and some others of Hoang Luu Thu Thuy (2012), Nguyen Van Hong (2017) deal with climate and bioclimate for agricultural and forestry development in Nghe An Province. Therefore, the tea growth in Nghe An should be detailedly studied in terms of the relationship between the bioclimatic diversity and this plant. Based on the recorded meteorological data and bioclimatic requirements of tea, the ability for growing tea is assessed at key site of Con Cuong district as well as the entire region of Western Nghe An. This result may be a useful contribution to the planning and development of tea cultivation in Nghe An province.

2. Study area and methods

2.1. Study area and its climate characteristics

The study area covers approximately 1.4 million ha of 11 districts, namely Thanh Chuong, Anh Son, Con Cuong, Tuong Duong, Ky Son, Que Phong, Quy Chau, Quy Hop, Nghia Dan, Thai Hoa, and Tan Ky, in the west of Nghe An, a province in the Centre of Vietnam (Fig. 1). The tea cultivation has been

significantly promoted in this region only since 2000s though it was known as one of the ancient regions for tea production in Vietnam. Con Cuong, for instance, is a major area of tea plantation with 388 hectares (Nghe An statistics, 2015). In this district, tea is greatly planted in the following communes: Chi Khe, Yen Khe, Bong Khe, Don Phuc, Binh Chuan, Cam Lam, Mau Duc and Thach Ngan. Tea is regarded as the plant for reducing poverty and even getting rich in many mountainous communes of Con Cuong district.

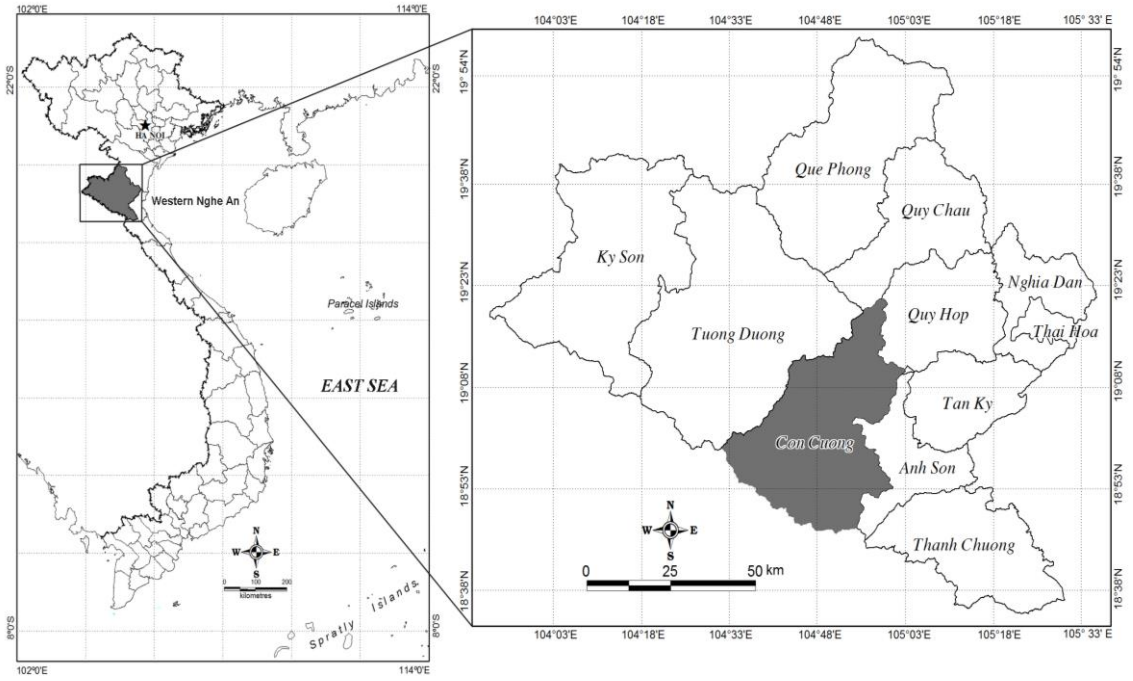

Figure 1. Location of study area

The climate of Western Nghe An is characterized by tropical monsoon with cold winter. The Truong Son mountain range strongly effects on monsoonal circulation, resulting in a great difference of local climate with two distinct seasons: hot, humid and abundant rainy summer, cold and little rainy winter. The average annual temperature is around 23-24°C, the altitude is below 100-200 m, corresponding to the total annual temperature of 8700°C. The temperature decreases gradually with altitude. The air temperature drops low, possibly to 0°C when the North East monsoon is active. The maximum temperatures can reach extremes values, in which the temperature is 42°C in low areas and 43°C in the closed valleys. The values of the maximum temperature are usually observed in April and May. This is also the intense activity period of hot dry west winds that bring the area hot dry days with high temperature and humidity can be as low as 30%.

The average annual rainfall fluctuates from 1000 mm to over 2100 mm with 120-150 rainy days. The rainfall in the midland is around 1500-1800 mm/year. The highest rainfall occurs in the mountainous areas at above 1000m in the northwest and southwest. The rainfall drops below 1200 mm in upstream of the Ca River and inside of the western valleys (Muong Xen: 1120 mm/year). The rainy season coincides with the summer monsoon season, lasting 6 months, from May to October. It is noticed that during the first few months of the rainy season, the rainfall

does not increase, even decreases to the minimum value in June. This monthly rainfall is only around 130-150 mm/month.

2.2. Bioclimate of tea

Tea, Camellia sinensis, is a species of Camellia genus, belonging to Theaceae family. Its leaves and buds are used to produce tea-the popular beverage in the world. Tea originated from East Asia, South Asia, and Southeast Asia with two major varieties, then the hybridization has created hundreds even thousands of cultivars overworld, but mostly distributed in the tropical and sub-tropical regions.

There have been many studies on the climatic impacts on tea cultivation, leading various results due to the difference in geographic location, cultivars, and other factors. Although tea can grow in a different climate, the most favorable conditions are warm-long daylength, high humidity, and night rain (Carr, 1972). Studying on some famous tea areas in mountains of China, Huang Shoubo (1991) found that quality and quantity of tea greatly influenced by the environmental factors such as geology, topography, climate, hydrology, soil, and vegetation. Among them, the most important is climate with its characteristics favoring tea growth such as more amounts of clouds and fog, less percentage of sunshine, abundant rainfall, high relative humidity, slow change (rise/fall) of temperatures, smaller daily and annual temperature ranges.

Originated from the sub-tropical region, tea can withstand high temperature with the total annual temperature of 4000°C (Nguyen Bao Ve, 2005). Therefore, the temperature is one of the most important environmental factors determining the growth, productivity, and quality of tea buds. A temperature ranging 13-30°C is favorable for tea growth; outside this range, the growth is diminished and even ceased (Bhagat et al., 2010). The optimal temperature for tea growth is defined as 18-30°C (Carr, 1972), 20-30°C (Huang Soubo, 1989) or at 22°C (Wijeratne et al., 2007).

Nguyen Bao Ve (2005) also pointed out: the favorable temperature for tea growth ranging from 22 to 28°C; slow growth from 10 to 18°C and from 30 to 40°C; very slow growth or cease below 10°C or above 40°C. Taton (1982) agreed that tea would stop shooting once the air temperature below 12.5°C. In Japan, the quickest growth of tea occurs at the temperature 30°C and growth stops at below 12.5ºC (Nakayama and Harada, 1962). The CO2 amount absorbed by tea attains a maximum at around 30-35ºC, dropping rapidly at 37ºC and photosynthesis stops at 42°C (Hadfield, 1976). Carr and Stephen (1992) pointed out the minimum temperature for tea shooting around 13-14°C. The daytime temperature over 30°C and the nighttime temperature below 14°C may slow down the tea growth. The daily amplitude of temperature also affects tea quality. In general, the high daily amplitude of temperature and low night temperature favor tea growth (Nguyen Bao Ve, 2005). Studying on the relationship between the monthly average temperature ranging in 22-28°C and tea productivity in Assam (India) shows that the tea yield still increases with gradually slowing rate when the temperature increases up to 26.6°C; it decreases once the temperature is over 26.6°C; at the temperature of 28°C, each 1°C increment of temperature may decrease 3.8% of tea yield (Ducan et al., 2016).

The tea growth requires annual precipitation around 1500-2000 mm. According to the Tocklai Tea Research Institute in India, precipitation of 1800 mm/y with temperature increase in cold period is most favorable for early tea crops (Sen et al., 1966). In contrast, the precipitation below 1150 mm/y is unfavorable for tea growth (Carr, 1972; International Center for Tropical Agriculture, 2017). The rainfall changes, either deficiency or excess, influence on the growth of tea. Therefore, the temporal distribution of precipitation in a year is more important than the total annual precipitation

(S. Ahmed et al., 2014; Bhagat et al., 2010; Carr, 1972). A rainfall of 100-150 mm/month is appropriate for tea (Nguyen Bao Ve, 2005; Carr, 1972). In Assam (India), the tea productivity drops gradually with the increase of monthly average precipitation, it is similar to the temperature change but in a smaller extent. For example, each 1mm increment of precipitation may decrease 1% tea yield (Ducan et al., 2016).

Due to the strictly climatic requirements, the tea yield and quality are also impacted by global climate change, including the strong fluctuation of climate factors and increasing frequency of extreme weather events such as heavy rain, storm, drought, hot sunshine. The tea farmers in southern Yunnan (China) have perceived the climate change, such as warmer temperatures and increased variation of rains and changing phenology of plants (i.e. growth cycles, flowering and fruiting seasons), directly impacting on tea plant (Ahmed, 2014). Higher temperatures are associated with the earlier harvest; extreme droughts thought to be more frequent in recent years are linked to tea leaves that are drier with less budding. Tea harvested during the drought also is purported to have a relatively more intense taste and aroma; whereas tea harvested during extreme rainy times has beautiful leaves with increased budding, but the relatively diluted taste and aroma. In addition, climate change has affected indirectly tea plant. Warmer temperature and shifts in of rainfall pattern also influence types and quantities of pests and weeds in tea gardens thus shifting the stress level of tea plants and thereby their phytochemicals.

2.3. Methods

- Statistics and analysis for climatic and bioclimatic data from 22 local gauge stations, especially 35-year data, from 1980 to 2014, on temperature and precipitation in 4 stations as Con Cuong, Tuong Duong, Quy Hop and Quy Chau.

- General survey and fieldwork in Con Cuong district: Investigating the current tea growth in the local climate with its components such as sunshine, air temperature, rainfall, humidity, wind regime and extreme events, which is harmful to tea.

- Determination of scientific name is taken by analyzing the following characteristics: plant form and flowers (Pham Hoang Ho, 2003). Based on the identification key (dichotomous key-referring to the published articles and monographs), the collected samples are scientifically named.

- Plotting of bioclimatic diagrams in accordance with Walter and Lieth (1967), and Nguyen Khanh Van et al. (2000). This diagram represents monthly variations of rainfall R (mm) and temperature T (°C) in an area with two vertical axes, the temperature in the left and rainfall in the right. These axes are scaled that each 10°C temperature corresponds to 20 mm rainfall in case of rainfall below 100 mm or corresponds to 200 mm in case of rainfall over 100 mm, so the scale is reduced by 10 times in the second case. Therefore, the temperature and precipitation curves in the diagram express the relationship between 2T and R, influencing the plant growth (Gaussen, 1954; Walter and Lieth, 1967):

$2T \geq R$: dry period for plant growth

$2T < R < 100$: humid period

$R \geq 100$: perhumid period

Moreover, the diagram is also supplemented with the following parameters: name and altitude of recording station, mean annual temperature, total annual rainfall, the number of monitoring year for temperature and rainfall, the absolute maximal temperature, the average maximal temperature of warmest month, the average minimal temperature of coldest month, the absolute minimal temperature, months with mean daily minimum temperature below 15°C and months with absolute daily minimum temperature below 5°C.

But we use months with absolute minimum temperature below 5°C and months with maximum temperature above 35°C in this

study instead of months with mean daily minimum temperature below 15°C and months with absolute daily minimum temperature below 5°C. The bioclimatic diagrams are built the areas: Con Cuong, Tuong Duong, Quy Hop, and Quy Chau in Western Nghe An Province, in which the bioclimatic diagram and characteristics in Con Cuong are used to evaluate the tea cultivability.

- Mapping and geographic information systems (GIS) are used to spatially differentiate climatic and bioclimatic factors in the whole region of Western Nghe An. The input data includes topographic maps, the monitoring data in many years at regional meteorological stations, maps of annual average temperature and total annual rainfall. The total annual rainfall and annual average temperature are firstly mapped in forms of main isotherms and isohyets. These values are calculated from monitoring data at gauge stations and then contoured with a consideration of temperature and rainfall changes due to topographic elevation. Based on the main isotherm and isohyet values, maps of annual average temperature and total annual rainfall are produced in form of digital raster by Inverse Distance Weight (IDW) interpolation supported by GIS software such as ArcGIS and MapInfo. Ombrothermic suitability for growing tea in Western Nghe An is zoned by integrating these maps with a consideration of climatic thresholds affecting tea growth.

The overall analysis procedure for this research includes data collection, fieldwork, bioclimatic analysis of tea, plotting and analyzing the bioclimatic diagrams, mapping climatic and bioclimatic factors and zoning ombrothermic suitability for growing tea (Fig. 2).

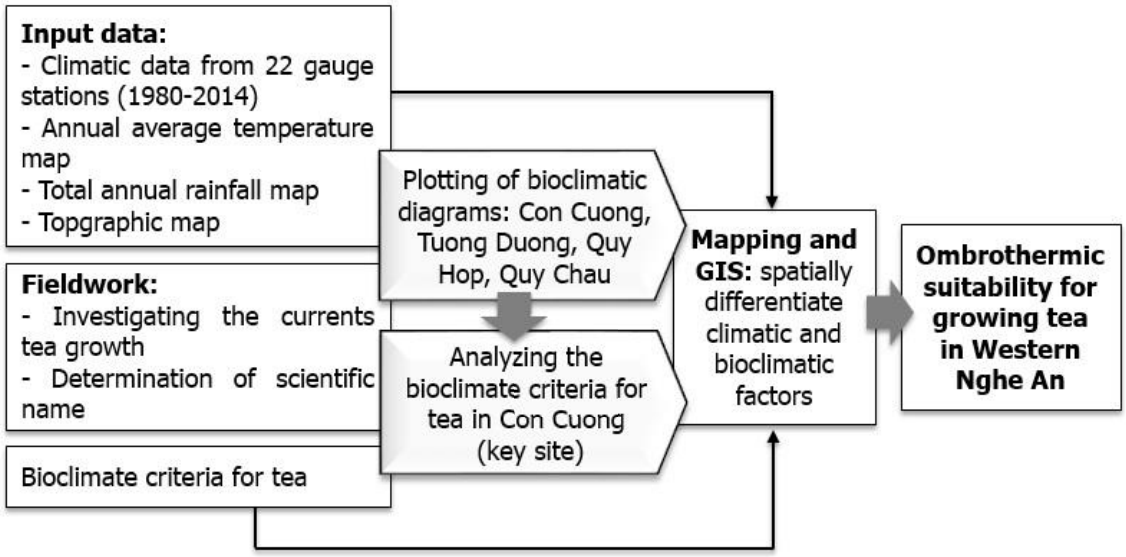

Figure 2. Analysis procedure for this research

3. Results and Discussions

3.1. Analyzing the bioclimate criteria for tea in Con Cuong

According to the field investigation, tea planted in Con Cuong are PH1, LDP1 and LDP2 cultivars. The PH1, recognized as national cultivar in 1986, is selected from the Manipur- Assam tea population imported from India. The PH1 has big buds, intense taste and aroma, so it could be served as raw material for producing black tea with rather

good quality, meeting the export demand. It is being cultivated in Bai Phu farm of Nghe An tea company.

LDP1 and LDP2 are two cultivars selected from F1 individuals, hybridized between Chinese great white tea with good quality and PH1 tea with strong growth. They were recognized by the Scientific Council of the Ministry of Agriculture and Rural Development as temporary cultivars in 1994. LDP1 was recognized as a national cultivar in 2003; LDP2 was piloted in Bai Phu tea farm (Anh Son - Nghe An) in 2004 (Nguyen Van Tao, 2004). LDP1 and LDP2 have a wide adaptability and moreover it can withstand drought and pests. This tea is capable for high yield. They have been planted in Con Cuong, Nghe An since 2000. Field survey in 2017 on three tea cultivars grown in Con Cuong showed that PH1 has larger buds, thicker leaves, but higher rate of mass loss than LDP1 and LDP2. The LDP1 and LDP2 buds are uncrushed when rubbing. The drought tolerance of LDP1 and LDP2 is better than PH1, but cold tolerance is worse. All three cultivars averagely yield 12-14 T/ha in rainy season and 8-10 T/ha dry season.

Effect of bioclimatic conditions on the tea growth in Con Cuong is analyzed on the basis of the bioclimatic diagram, expressing the relationship between the precipitation R (mm) and the temperature T (°C) (Fig. 3):

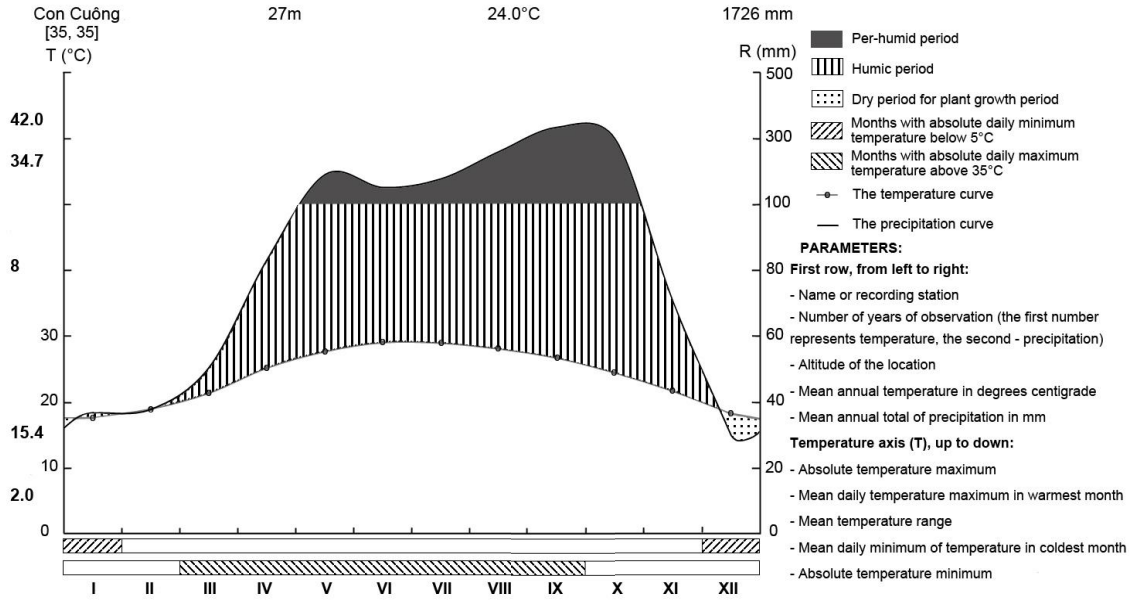

Figure 3. The bioclimatic diagram at Con Cuong

- December and January are in dry period; the temperature curve is above the precipitation ($2T \geq R$). Although these are the coldest months, the monthly average minimum temperature is still in the range of tea growth. However, the temperature sometimes falls below the favorable limit (13°C), the absolute minimum temperature is recorded at 2°C. Therefore, in general, tea slowly grows and mostly maintains its survival in this dry period. Watering for tea is needed in these months.

- In February, March, April, and November are the humid period; the precipitation curve lies below 100 mm but above the temperature curve ($2T<R<100$). The rainfall and temperature conditions are the most favorable for tea growth in a year. According to the investigating results, the tea production has its best quality and highest yield of 12-14 T/ha in

this humid period of February, March, April, and November.

- From May to September is the perhumid period, the rainfall curve is above 100 mm. Therefore, it needs to drain off water to avoid the inundation of the tea garden. In addition, months from May to August are the hottest period with monthly average maximum temperature around 33-34°C and temperature over 35°C in 10-15 days, negatively affecting the tea growth and photosynthesis. The highest absolute maximum temperature is recorded at 42°C, reaching the photosynthetic limit.

In recent years, the hot weather with drought has extremely affected tea growth and productivity. For example, 100 ha in total 350 ha of tea area in Yen Khe, the major tea plantation in Con Cuong district, were dead in the droughts of 2012 (http://baonghean.vn). Furthermore, the high temperature without rain in more than 1 month in 2015 affected 70% area of newly planted tea as well as some other tea area in Yen Khe (http://nghean.gov.vn). Field investigation shows that the hottest months of May and June influence harmfully the tea growth and quality, decreasing the productivity to 6-8 T/ha. The excess rain in July and August may inundate the tea gardens. This is the period of water excess, tea grows more slowly, giving decreased quality.

In terms of temperature, the annual temperatures in Con Cuong averages at 24°C, falling downs to 20°C, 18°C, 15°C at the higher altitudes from 700m, 1100m and 1700m respectively. The monthly average temperature fluctuates from 18 to 29°C (Fig. 3). In general, the monthly and yearly average temperatures are favorable for tea cultivation in Con Cuong; the most favorable conditions for tea are below 1,100m of altitudes. Both the mean minimum temperature of the coldest month above 15°C and the mean maximum temperature of hottest months below 35°C are in the temperature range of tea growth.

In terms of precipitation with an average value over 1700 mm/year, Con Cuong is relatively suitable for tea plant. The precipitation curve (Fig. 3) has two peaks in May and September in the perhumid period. The precipitation increases gradually from 37mm in January and reaches a top at 190mm in May due to the period of minor rain. Then, it falls to 150 mm in June, and continuously rises up to 300 mm in September, and drops to 30 mm in December. For tea cultivation, the monthly distribution of precipitation plays a more important role than the total annual precipitation (Carr, 1972; Bhagat et al., 2010; Ahmed et al., 2014). If taking the value of 100-150 mm as favorable monthly rainfall for tea, only June could meet this criterion. The other months are either deficiency or excess in precipitation, more or less negatively influencing the growth of tea.

3.2. Ability of tea growth in Western Nghe An

Bioclimatic evaluation of ability for growing tea in West of Nghe An is based on the annual average temperature and the total annual precipitation calculated from data recorded at gauge stations within the region and its adjacencies. Based on meteorologically monitored data and climatic requirements of tea, the following thresholds are determined:

- The annual average temperatures are recorded around 23-24°C at meteorological stations. Therefore, the whole region is situated within the favorable temperature range for tea growth (13-30°C), in which the favorable temperature range from 18°C to 30°C (Carr, 1972). As a result, 18°C is chosen as the threshold distinguishing less favorable (13-18°C) and favorable temperature (18-30°C).

- The annual total precipitations recorded at meteorological measuring stations range from 1100 mm to 2100 mm. The minimum precipitation for tea defined by Carr (1972) as 1150 mm/year; the most favorable rainfall suggested by Nguyen Bao Ve (2005) is around 1500-2000 mm/year. Therefore, the value of 1150 mm/year is chosen as a threshold separating unfavorable class and

other more or less favorable, which is in turn divided into favorable class in the range of 1500-2000 mm/year and the less favorable outside this range.

According to the above-mentioned bioclimatic criteria, the Western Nghe An can be divided into 5 distinctive bioclimatic areas with different suitability for tea growth (Fig. 4, Tab. 1):

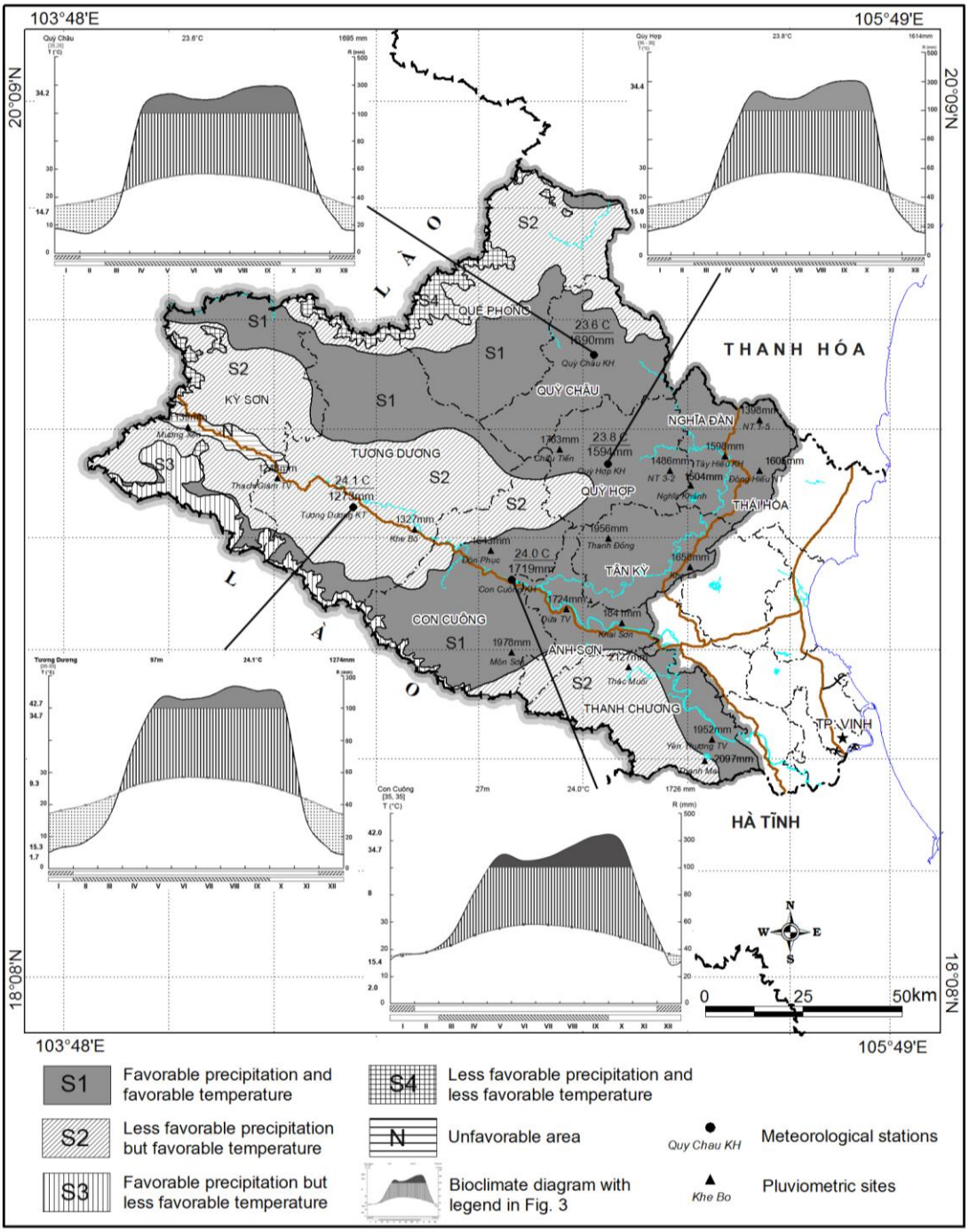

Figure 4. Ombrothermic suitability for growing tea in Western Nghe An

Table 1. The distribution of areas based on the ability of tea growth

No	Areas classified by ability of tea growth	**Area** (Hectares)	**Percentage** (%)
1	The favorable precipitation and favorable temperature	746,355.67	54.15
2	The less favorable precipitation but favorable temperature	538,622.68	39.08
3	The favorable precipitation but less favorable temperature	41,881.69	3.04
4	The less favorable precipitation and less temperature	37,126.49	2.69
5	The unfavorable area	14,411.82	1.05
	Total	**1,378,398.35**	**100.00**

- The favorable precipitation and favorable temperature: The precipitation is within 1500-2000 mm/year and the annual average temperature is above 18°C.

- The less favorable precipitation but favorable temperature: The precipitation is within 1150-1500 mm or above 2000 mm/year, and the annual average temperature is above 18°C.

- The favorable precipitation but less favorable temperature: The precipitation is within 1500-2000 mm/year and the annual average temperature below 18°C.

- The less favorable precipitation and also less favorable temperature: The precipitation is within 1150-1500 mm or above 2000 mm/year and the annual average temperature below 18°C.

- The unfavorable for tea growth: the annual average precipitation is below 1150 mm/year.

In general, the ombrothermic conditions in Western Nghe An are favorable for tea growth, however, the favorability is spatially differentiated.

The areas of favorable precipitation and favorable temperature accounted for 54.15% of total Western Nghe An (746,355.67 ha). This is the most favorable areas for growing tea, distributed mainly in Con Cuong, Anh Son, Tan Ky, Quy Hop, Quy Chau, the Southern Tuong Duong and Northern Que Phong, where the meteorological data express very favorable for tea: rainfall of 1600-1700 mm/year; yearly average minimum temperature of 20.5-21.1°C; and yearly maximum temperature of 29°C. However, the meteorological data at Con Cuong, Quy Chau, and Quy Hop stations show that there a dry period of 2 to 4 months for plants. Irregularly distributed precipitation during the year causes a water shortage in dry season and water excess in the rainy season. The precipitation is less than 100 mm/month from November to April (except April in Quy Chau), whereas it exceeds 150 mm/month from May to October (except June in Con Cuong), so the only rainfalls with around 100-150 mm/month in April at Quy Chau and in June at Con Cuong is most favorable for tea growth. All the months left are less suitable or unsuitable due to the insufficient or excessive rains.

Months from April to September are hot with average maximum temperature over 30°C, especially from May to August with temperature up to 33-34°C, decreasing the growth of tea. Furthermore, there are many extreme hot days with a temperature over 35°C in these months. According to the data at gauge station of Quy Chau, Quy Hop, and Con Cuong, every year, the region is subject to 55-65 extreme hot days. Most of them concentrate from May to August with 44-52 days, account for 80% of the total. In these days, not only tea, but also many other plants may be withered.

The areas of less favorable precipitation but favorable temperature accounted for 39%, mainly distributed in Thanh Chuong, Tuong Duong, Ky Son, and Northern Que Phong. These are favorable areas for tea, but in a level lower than previous areas because the total annual precipitation is lower than a suitable threshold such as Tuong Duong, Ky Son or higher than a suitable threshold such as Thanh Chuong and the North of Que Phong.

The areas of relatively low precipitation in Tuong Duong and Ky Son are also subject to a long dry period for growth of plants. The bioclimatic diagram in Tuong Duong expresses this period lasting up to 5 months, from November to March. In the rainy season, from May to October, monthly precipitation exceeds the threshold of 150 mm/month for tea growth. However, this excess is not too much, except in September and November, so it could be considered as relatively suitable conditions. The variation of monthly average maximum temperature goes around 32.2-34.7°C from April to September, which is also the time of 74 extremely hot days with temperature over 35°C, accounting for 89 % of the yearly total. Therefore tea grows badly and may be withered in this period, especially in May, June, and July when the temperature keeps 35°C more or less in half of the months.

The areas of favorable precipitation but less favorable temperature occupy 41,881.69 ha, i.e. 3.04% of total area. They are located in the Northwest-Southeast mountainous range, along with Vietnam-Laos border and in Southwestern Ky Son, Tuong Duong and Con Cuong districts, characterized by an annual average temperature below 18°C. Despite the absence of meteorological stations, as a result of interpolation from the stations of Tuong Duong and Con Cuong situated on foot of the mountain, these areas may be subject to the cold days with temperature below 13°C, a lower threshold, causing the slow even ceased growth of tea. The absolute minimum temperatures are recorded of 1.7°C at Tuong Duong station, situated on an altitude of 97 m and 2.0°C at Con Cuong station situated on an altitude of 27 m. Therefore, the respective temperature in the higher elevation of these areas must be lower.

The areas of less favorable precipitation and less temperature account for 2.69% of the total Western Nghe An. They are limited in high mountainous parts of Vietnam-Laos border, belonging to western Ky Son, northern Tuong Duong, and northern Que Phong. Although there is no meteorological measuring station, the temperature must be very low in winter because of its very high position. In the winter, the temperature may drop under 13°C, causing the slow even ceased growth of tea. The total annual average precipitation, around 1150-1500 mm/year in western Ky Son and above 2000 mm/year in the northern Tuong Duong and northern Que Phong, is out of the suitable range for tea growth, thus the tea cultivation in these areas is not recommended.

The unfavorable areas for tea growth account 1.05% of the whole region. They are distributed along Ca River Valley in Ky Son District, obscured by numerous mountains such as Pu Hoat, Bu Khang in the North, Pu Lai Leng in the West. Consequently, the areal precipitation is below 1150 mm/year, the minimum limit for growing tea. Based on the meteorological data at Muong Xen station (Ky Son District), it hardly rains in December, January, and February, the rainfall here is only 6 mm/month.

Generally, the spatial differentiation of annual average temperature and total annual precipitation in western Nghe An results in four arable areas of the tea plant. Among them, the most favorable area accounts for 50% of the regional area, the three rests are less favorable in terms of either precipitation or temperature. The monthly variations of precipitation and temperature express some climatically adverse impacts on tea plant in certain moments of the year.

The climatic disadvantages for this region mainly include temperature either below 13°C or above 35°C, rainfall over 150 mm/month, dry period for tea growth. They could be mitigated by applying some measures such as appropriate irrigation, cold and hot prevention, seasonal caring techniques and selection of adaptive cultivars. The ombrothermic diagrams and the maps expressing the differentiations of temperature and precipitation in space and in time are the

important bases for planning and development of tea cultivation. However, this assessment is on The climatic disadvantages for this region mainly include temperature either below 13°C or above 35°C, rainfall over 150 mm/month, dry period for tea growth. They could be mitigated by applying some measures such as appropriate irrigation, cold and hot prevention, seasonal caring techniques and selection of adaptive cultivars. The ombrothermic diagrams and the maps expressing the differentiation of temperature and precipitation in space and in time are the important bases for planning and development of tea cultivation. However, this assessment is only based on bioclimatic approach. A thorough assessment needs more study in other aspects such as terrain, soil, and socioeconomics. ly based on bioclimatic approach. A thorough assessment needs more study in other aspects such as terrain, soil and socioeconomics.

4. Conclusions

The survey, sampling, and bioclimatic analysis show that the ombrothermic conditions in Con Cuong are relatively favorable for tea growth. In order to obtain high productivity, the climatic disadvantages should be taken into accounts such as arid and cold weather in December and January, hot sunshine from May to August, and abundant rain from May to September.

Spatial differentiation of annual average temperature and total annual precipitation in Western Nghe An can be grouped in 5 areas: one unfavorable and four more or less favorable for growing tea, in which, the most favorable area accounts for 50% of the total region, three rests are less favorable in terms of either precipitation or temperature. However the fours areas favoring tea growth, in certain moments of the year, are also subject to weather disadvantages such as temperature is either below 13°C or above 35°C, precipitation over 150 mm/month, dryness for growth, etc. These adverse impacts could be mitigated by applying the measures such as appropriate irrigation, cold and heat prevention, seasonal caring techniques, selection of adaptive cultivars. A thorough assessment for effectively growing tea needs more study on bioclimatic differentiation in space and in time, i.e. in months of the year. In addition, the ability of tea growth in Western Nghe An should be assessed not only from bioclimatic view but also other aspects such as terrain, soil and socioeconomic criteria.

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