Managing Climate Risk in a Major Coffee-Growing Region of Indonesia

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Abstract

Indonesia is currently one of the top four coffee exporting countries in the world. Climate change is projected to cause significant impacts on coffee. Without proper adaptation measures, this will significantly lower the productions. Changes in rainfall and increases in temperature will affect the phenological development that would eventually influence yield and quality of crop including the potential risks of pest and disease attacks. Assessment in Toba, a major coffee-growing region of Indonesia, indicated that in the middle of this century (the 2050s), under climate scenarios of RCP4.5 and RCP8.5, suitable areas for coffee production would decrease significantly. The average yield is projected to

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decrease between 25% and 75% of the current yield. However, the highlands that are currently not suitable for coffee (>1500 m above mean sea level) is projected to become suitable with a higher yield than the current. A significant increase in rainfall during the rainy season and prolonged dry season will also affect coffee phenological development. It will shift the peak of coffee flowering and harvesting seasons in Toba. The severity of the coffee berry borer *Hypothenemus hampei* (Ferrari) attack will also increase in the future. The current crop management farming practices should be adjusted and improved to adapt to such change.

Keywords
Climate change · Climate scenarios · Indonesia · Toba region · Coffee · Climate change adaptation · Coffee berry borer

5.1 General Condition of Toba Region

5.1.1 Biophysical Conditions

Toba region is located in North Sumatra Province, Indonesia. The main coffee-growing region in Toba is located around Lake Toba, with total area of about 69,854 ha. The area is geographically spanned within 2°21′32″–2°56′28″N and 98°26′35″–99°15′40″E situated in the districts of Samosir, Toba Samosir, Dairi, Karo, Humbang Hasundutan, North Tapanuli, Simalungun and West Pak-Pak (Ministry of Environment 2014). Hilly and mountainous areas, ranging from 600 to 1800 m above mean sea level (Fig. 5.1), dominated the topographical condition of Toba, with slope varying from extra gentle (0–8%), gentle (8–15%), critical (15–25%), steep (25–45%) and extra steep (>45%). The northern part of Lake Toba (Tanah Karo) has relatively smaller water catchment areas with extra steep hillsides, whereas Samosir Island has larger catchment areas and extra gentle slope (<3%). The central part of the island is relatively extra steep mountainous area with slopes ranging from 30.5% or even in some areas more than 75% (Ministry of Environment 2014).

The soil type in the area was likely formed by Toba acidic tuff parent material under cold climatic condition. Both factors generally formed andosol. Other materials such as sedimentary rocks, bedrocks and alluvial deposits were also found forming other major soil groups like cambisol, podzol and regosol. Table 5.1 and Fig. 5.2 below provide detailed characteristics of each soil type.

In general, Cambisol (Dystrudept and Eutrudept), Andosol (Dystrandept) and Podzolic (Tropudult) soil types dominated the Toba Region. The soils have relatively low to medium level of fertility, high acidity, rough texture and low nutrient content. The area within Sinabung Mountain has a medium level of fertility. Therefore, the chemical characteristics of the soils must be improved through liming, fertiliser application and replenishment of organic materials, e.g. compost from rice straws, cacao shells or manure. These would increase the N level, as well as improve the soil quality, physical, chemical and biological characteristics.

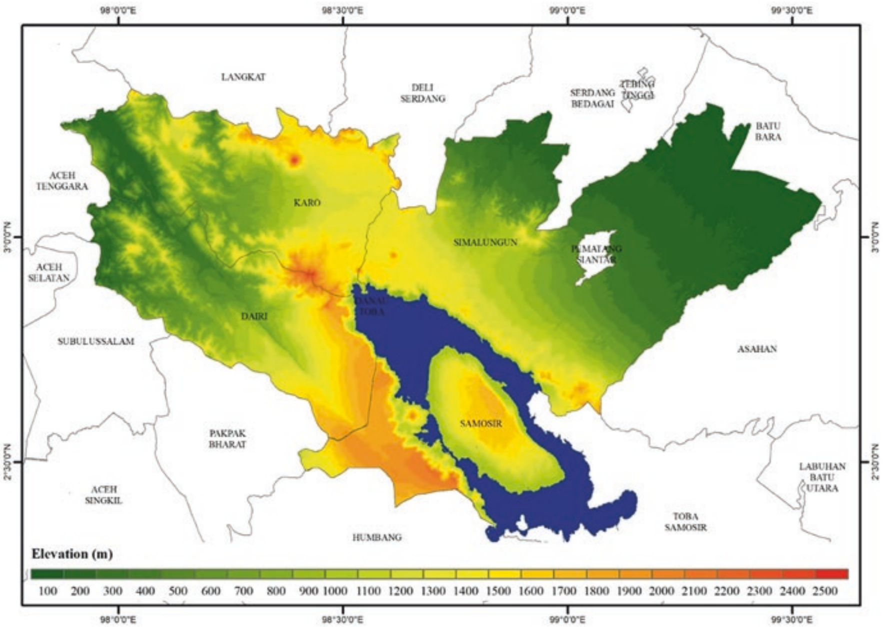


Fig. 5.1 The topography condition of the Toba Region

5.1.2 Socio-economic Conditions of the Small Holder Coffee Farming in Toba Area

The majority of Toba people engage in farming activities. Agriculture has long been their primary source of income. Agriculture, plantation and fisheries contribute to about 55% of the gross regional domestic products (Ministry of Environment 2014). Among the plantation commodities, coffee is the top of the list – well-known specialty coffee from the area including Kopi Sidikalang from Dairi and Kopi Simalungun from Simalungun. The number of coffee farm households in the four main coffee-growing districts Simalungun, Dairi, Karo and Samosir totalled to 17,036; 14,783; 6800; and 5202 families, respectively.

Statistic reports showed that Dairi District has the largest smallholder coffee plantation among the four districts, while the smallest is found in Samosir District (Table 5.2). The entire coffee plantations under study were about 29,500 ha, which accounted to more than 50% of the total coffee plantations in North Sumatra Province. Data from the years 2011–2016 have indicated that there was no significant increase in the total area of coffee plantations in Dairi, Samosir and Simalungun Districts, with an annual increase rate approximately 0.1–2.6%. On the contrary, on an average, the total plantations in Karo District have increased by 8.2% annually during these periods, indicating a relatively high expansion of coffee plantations.

Table 5.1 Soil types found in Toba area

Soil type (Center for Soil Research, 1978, 1982)	Taxonomy (USDA 1975–1990)	Characteristics
Andosol	Dystandept or Hydrandept	Has andic properties
		Content weight < 0.85 g/cm^3
		High organic material
		Allophane amorphous minerals dominate the clay fraction
		Generally categorised as fertile and has good physical properties; therefore it is common for horticulture and tea, quinine and tobacco plantations
		The andosol in the study area has relatively low fertility, rough texture, low cation exchange capacity, low base-saturation ratio and low water storage capacity
Cambisol	Dystrudept, Eutrudept, Andaquept, Tropaquept or Humitrudept	Categorised as the soil in early development phase
		Parent material varied and distributed from flat to mountainous areas, from wet to dry climate
		Cambisols found in Toba area are dystric cambisol and eutric cambisol
		In the area near water, soil colour tends to be greyer;
		Ata higher elevation with less influence from the water surface, the soil is known brownish to reddish, has a horizon of cambic and a base-saturation ratio < 50%
		The soil of this character is known as Dystrudept, and when the base saturation ratio is >50%, it is called Eutrudept
Podzolic	Tropudult	Has typically gone through the advance weathering process
		Clay translocation from upper to lower layers is obvious
		Categorised as acidic to very acidic soil
		Has low base saturation ratio and cation exchange capacity (CEC)
Regosol	Tropopsamment	Very young mineral soil
		Has a coarse texture of albic material
		Generally has low CEC, low water storage capacity and highly fast infiltration
		Commonly found in Samosir Island

(continued)

Table 5.1 (continued)

Soil type (Center for Soil Research, 1978, 1982)	Taxonomy (USDA 1975–1990)	Characteristics
Alluvial	Tropaquept or fluvaquent	Formed from the settling process of rivers, lakes and the process of colluviation at the bottom of hills
		Categorised as young soil and associated with a wet environment
		Also, this type of soil does not have a unique character/horizon, texture ranging from fine to coarse with relatively low nutrient content

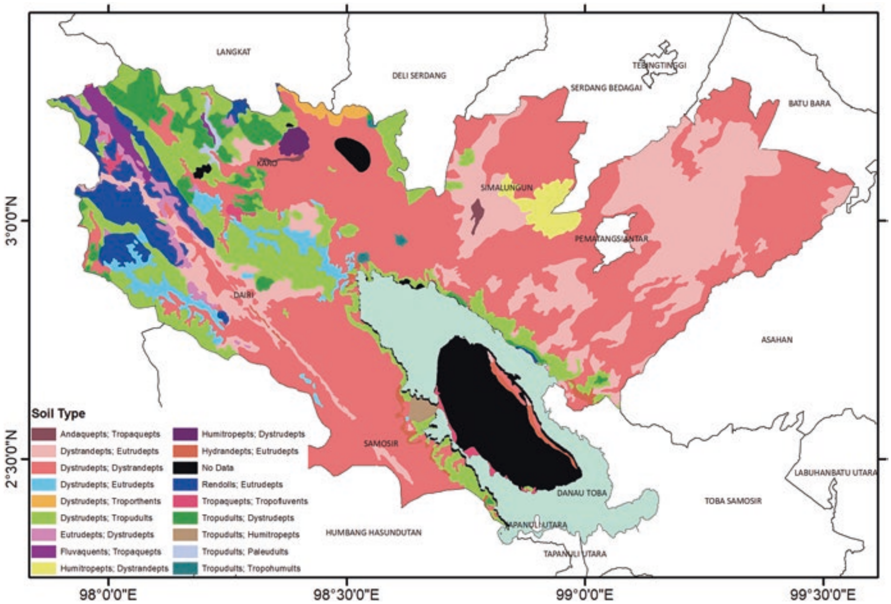


Fig. 5.2 Soil types within the Toba area

The coffee productivities in all study areas were relatively high. The average production in Simalungun Districts were 1.4 t/ha, while in Dairi was 0.85 t/ha and Samosir was 1.1 t/ha (Table 5.3). These level of yield are close to the national average (Ministry of Agriculture 2017).

Table 5.2 Average harvested area and production of coffee in 2011–2016

District	Total area (ha)	Production (tonnes)	Annual expansion rate (%)	Sub-districts with contribution >80% to the district production
Dairi	10.500	8.478	0.1	Sumbul dan Parbuluan
Karo	6.834	5.380	8.2	Merek, Simpang Empat, Barusjahe, Tiga Panah, Munte, Juhar, Payung, Naman Teran, Kutabuluh
Samosir	4.468	3.303	2.6	Rongurnihuta, Pangururan, Palipi, Simanindo, Sianjur Mulamula, Nainggolan
Simalungun	7.698	9.597	2.4	Purba, Raya, Pamatang Silimahuta, Dolok Pardamean, Dolok Silou, Silimakuta, Sidamanik, Girsang Sipangan Bolon

Source: District and sub-district statistics (BPS 2016a, b, c, d)

Table 5.3 Average production of Arabica coffee in Toba Region

District	Total area (ha)	% TM	Area of TM (ha)	Production (ton)	Yield (t/ha)
Dairi	10.500	95	9.975	8.478	0.85
Karo	6.834	85	5.975	5.380	0.93
Samosir	4.468	63	2.831	3.303	1.17
Simalungun	7.698	84	6.495	9.597	1.47
Average					1.07

Source: Office for plantation of North Sumatra Province (2016). TM: Productive Coffee (already berry producer)

5.2 Existing Coffee Farming Practices

Assessment of existing coffee farming practices in Toba area was conducted through survey and interview of 205 farmers distributed in the four districts. All of their farmlands are located in the elevation of between 600 and 1500 m MSL (Fig. 5.3). The topographical conditions of the farmlands vary from flat to very steep slopes. About 84.4% of the smallholder plantations in the four districts are located in relatively low slopes (flatlands; area with slope < 3%), 16% downhill as an area with slope ranging from 3% to 15% and 2% in very steep areas (slope > 15%).

5.2.1 Cultivation Practices

5.2.1.1 Historical Record

There were no formal records on the periods of coffee introduction and cultivation in the study area. The earliest substantiated evidence of coffee-growing as stated by the respondents appeared to be dated back before 2000, while few others indicated that coffee cultivation in the areas started after 2000. According to the respondents, the oldest plantation in the area has reached the age of 25 years. In general, coffee

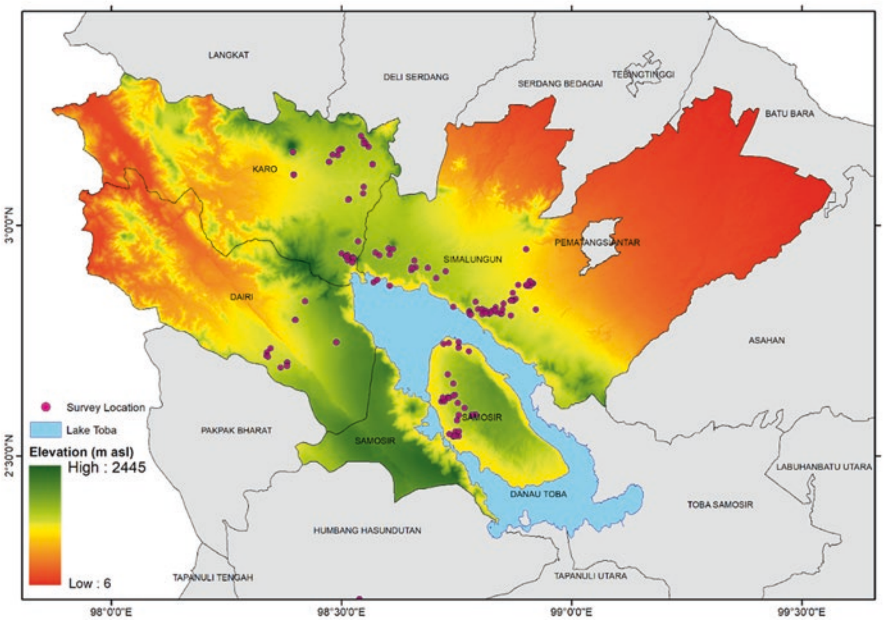


Fig. 5.3 Distribution of respondents (dot) according to elevation (m.MSL)

has been widely cultivated by the communities in the past 15 years. The age of the coffee plantations in the four districts was between 4 and 15 years. The Indonesian Coffee and Cocoa Research Center (Puslitkoka 2013) identifies that coffee is most productive between 5 and 20 years of age. Trees over 20 years of age could no longer yield fruits, and the production is 30% lower than the younger coffee trees. Morphologically, matured coffee trees have larger rod shape and tend to be porous.

Compared to the yield of the superior national coffee varieties such as S-795 and Andung Sari, the Toba coffee production is much lower. At large, the average yield of coffee in the Toba Region was found to decrease at an age above 10 years (Fig. 5.4), a similar condition found for the Andung Sari variety. On the contrary, the production of S-795 variety increases with increasing age even reaches 20 years.

5.2.1.2 Arabica Coffee

The coffee cultivars in the study areas originated from the following varieties: Katimor Sigararutang (KS), Ateng Super (AS), Katimor Andung Sari (KAS), Katimor-Ateng (KA) and Katimor-Ateng Jaluk (KAJ). Robusta is also cultivated in few areas. Figure 5.5 presents the predominant varieties cultivated in Karo and Simalungun District. In Samosir, the Ateng Super is the most dominant. Some farmers planted more than one variety.

The combination of KS and KA was identified as having the highest production at tree/plant category (Fig. 5.6), with production reaching 1 kg/tree, while other varieties like AS, KAS and KAJ could only yield <1 kg/tree. The population per ha varies from 100 to 3000 trees, with some farmers are planting more than 3000 trees per ha.

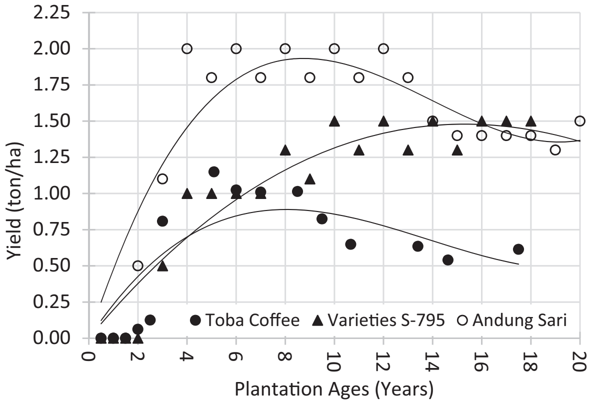


Fig. 5.4 The average yields of coffee in Toba Region compared to superior national varieties S-795 and Andung Sari

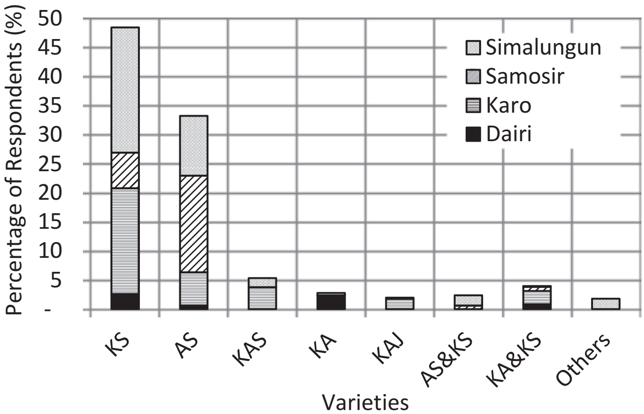
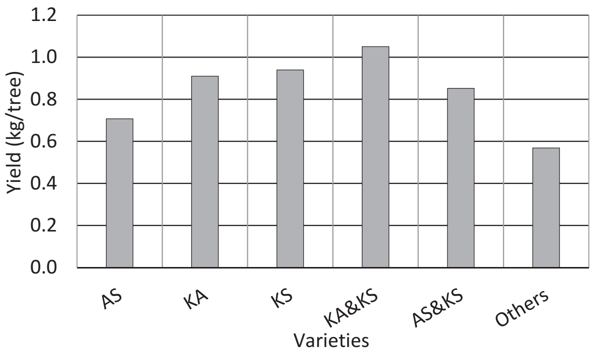


Fig. 5.5 Main coffee varieties planted in the Toba Region

Fig. 5.6 Yield by variety



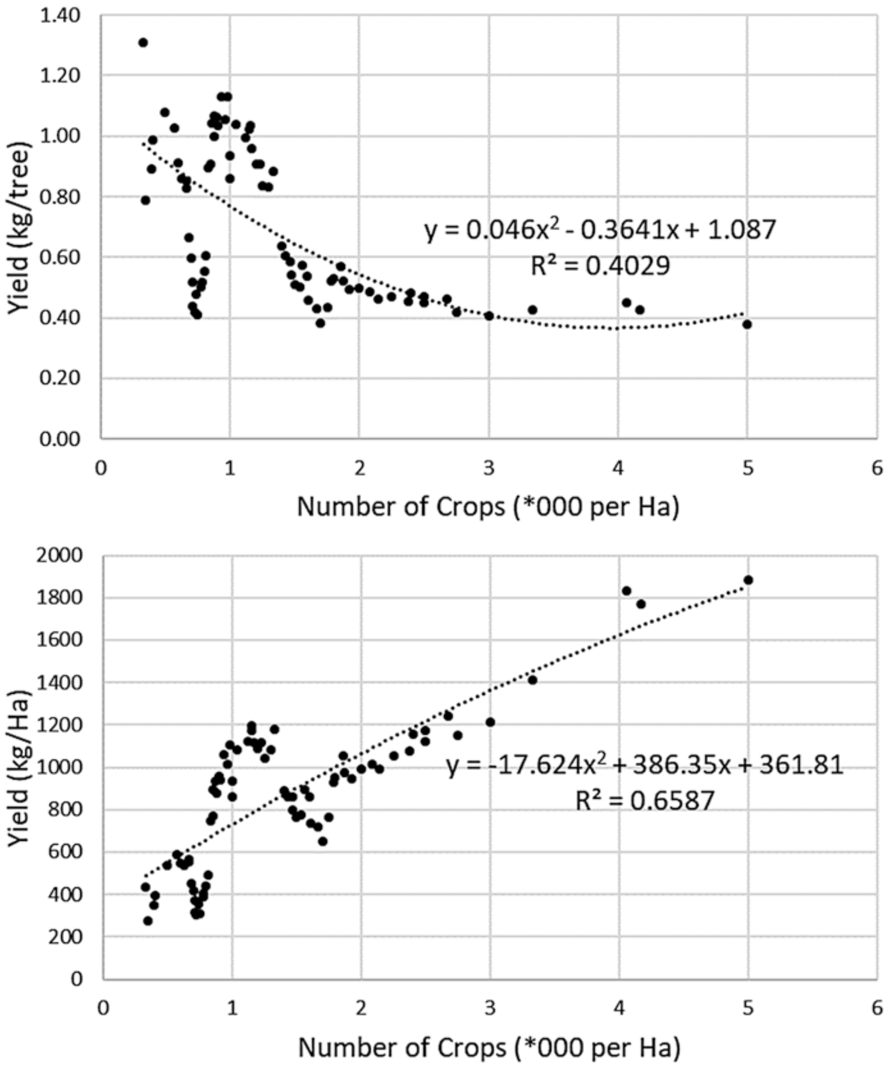


Fig. 5.7 The yield of Toba coffee vs the number of crops per hectare (production is calculated based on moving average of ten data sorted from smallest to largest land ownership)

The average land ownership area ranged between 0.06 and 4.0 ha, or on an average 0.6 ha. In general, the results showed that production lowers with an increasing number of crops per hectare (Fig. 5.7). The survey revealed that production of Arabica coffee in the four districts ranged from 0.3 t/ha to 1.9 t/ha or on an average about 0.864 t/ha. These numbers were slightly lower than those reported by the Office for plantation of North Sumatra Province.

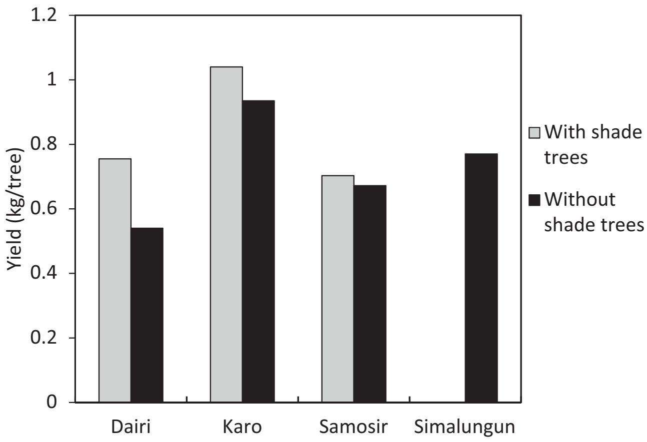


Fig. 5.8 Yield of coffee with and without shades

Seeds were obtained from farm shops, exchanges between farmers, farmers own breed or plantation office. Currently, the use of uncertified seeds has led to untraceable sources of the seeds. The respondents reported that the most productive seeds were those originated from grafting.

5.2.1.3 Cultivation Techniques

Traditional polyculture is the most common practice of coffee cultivation in the study area, with planting space ranging from 1.5 × 1.0 m to 3.0 × 4.0 m or total population per hectare ranging from 100 to 2750 trees. Few farmers are practicing monoculture with planting space ranging from 1.5 × 1.0 m to 2.0 × 4.0 m or a total of 200–2750 trees/ha.

In polyculture plantations, farmers often cultivate coffee with candlenut, palm and coconut; fruits such as avocado, mango, durian and banana; or other woody plants. Coffee planted in monoculture often experienced a higher intensity of light that leads to *biennial bearing,* a period, in which crops bear dense fruit in one period and followed by the rapidly declining intensity of flowering and fertility in the next period. Recommended protection crops include *Leucaena leucocephala* (lamtoro) and *Gliricidia maculata* (Gliricidia) and other crops from Leguminosae family. Results of the survey indicated that the production of crops was higher under specific intensity of shades, compared to crops without shades (Fig. 5.8). In a number of young or unproductive coffee plantations, farmers also planted annual seasonal horticultural crops, such as shallots and scallions.

A key aspect in coffee cultivation that plays an essential role in production, both in quality and quantity, is maintenance. Maintenance includes fertiliser application, pruning, weed control, pests and diseases control, irrigation, mulching and regulating protective plants. Most coffee farmers in the study areas have not practised this comprehensive process. The fertiliser is not regularly applied because the farmers did not have sufficient funding to cover the production costs, in addition to the long

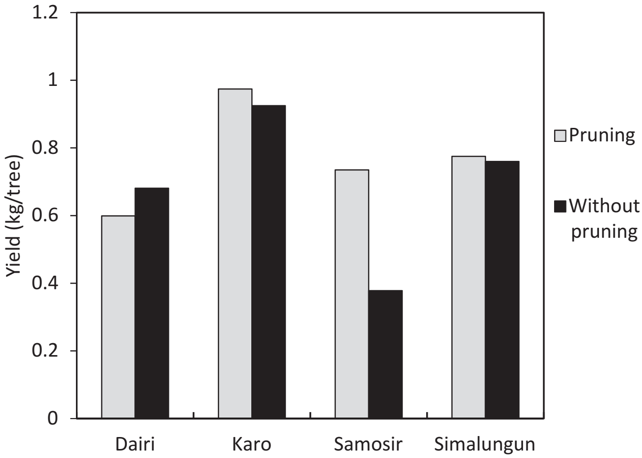


Fig. 5.9 Yield of Arabica coffee with and without pruning

distance of farm shops that sell production inputs or just because the farmers think that their plantations still produce reasonable yields without the need for additional fertiliser. Crops without additional nutrients from fertiliser would tend to grow dwarf and produce yellow crown and poor branching.

Pruning is also a vital maintenance process to ensure sustainable coffee production, which would include removing unproductive parts of the plants, e.g. shoot water, small branches that grow on the trunk, suckers and all diseased branches. The top parts of the trees were often cut to keep its height to be less than 1.8 m. Pruning also allows trees to be easier to harvest, and provides well-regulated light and air. Farmers in the study areas have not performed regular crop maintenance practices. Pruning is frequent, but not conducted on a regular basis. The farmers did not entirely understand which part of the plants that required rejuvenation to stretch the lifespan of the coffee tree and hence increase production. Unpruned trees tend to grow moult and leafless branches and produce less flowers and fruits, where, on the contrary, pruned trees would produce higher yields (Fig. 5.9).

Weed control is another central process in coffee cultivation. This maintenance process is best conducted, when the plants are in their early growing stage, has relatively open space and direct sunlight reaching the ground, thus enabling the environments to spur weed growth. The frequency of weed control can necessarily be reduced to productive/yielding plants, as the plant's canopy has grown thick and close to each other. Farmers in the study areas mainly performed weed control manually using a hoe on immature or yielding plants (Fig. 5.10).

Irrigation and mulching of coffee plantation are essential, especially during the dry season. Irrigation is not only useful for regulating water supply to support plant growth but also during flowering and fruits development. The Samosir District often experiences longer dry season, so it needs more intensive irrigation than other areas. Irrigation water is supplied from Lake Toba, and pumped up to the surrounding hilly

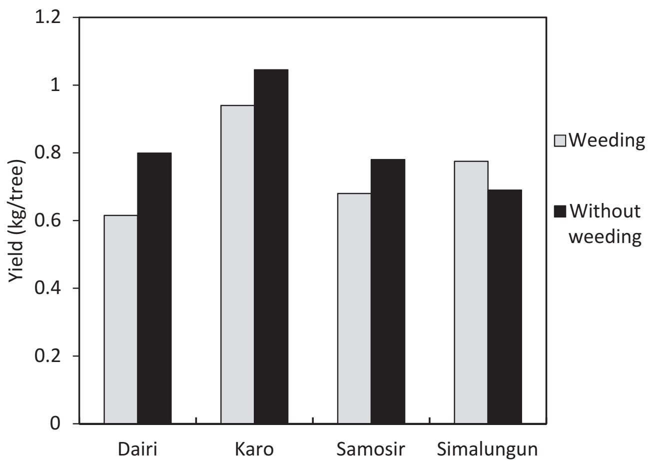


Fig. 5.10 Yield of Arabica coffee with and without weedings

Table 5.4 List of common coffee pests and diseases in the study areas

No	Coffee pests and diseases	No. of farmers	Percentage (%)
1	Coffee berry borer/CBB	166	81.0
2	Green scale	12	5.9
3	Coffee stem borer	10	4.8
4	Leaf buds/*Helopeltis* sp.	7	3.4
5	Coffee leaf rust	5	2.4
6	All plants dried and died	2	1.0
7	Branches dried	1	0.5
8	None of the above	2	1.0

areas. Mulching the grounds are necessary to reduce evaporation. Traditionally, the farmers would use weeding wastes, pruning wastes, or other materials found in the garden for mulching.

5.2.2 Pests and Diseases

5.2.2.1 Type of Common Pests and Diseases and Their Damage Rate

Plant disturbing organisms like pests and diseases, are among other factors that inhibit the growth of coffee, both in quantity and quality. In general, coffee berry borer (*Hypothenemus hampei* Ferr.) (CBB) is known as the primary pest found in the study areas. More than 80% of the respondents have also indicated other main pests, such as green lice, stem borer, leaf buds and leaf rust (Table 5.4). The highest number of coffee berry borer outbreaks was found in Simalungun and Samosir Districts while the least was found in Karo and Dairi Districts (Table 5.5). Coffee berry borer is common to attack nearly all coffee varieties including Arabica,

Table 5.5 Pests and diseases outbreaks experienced by farmers in the study areas

Coffee pests and diseases	No. of farmers (%) Dairi	Karo	Samosir	Simalungun
Coffee berry borer	68.8	69.6	84.4	93.1
Green scale	9.4	8.9	2.2	4.2
Coffee stem borer	12.5	5.4	6.7	0
Leaf buds/*Helopeltis* sp.	3.1	7.1	4.4	0
Coffee leaf rust	0	7.1	0	1.4
All plants dried and died	0	0	2.2	0
Branches dried	0	1.8	0	1.4

Number of respondents in each district of Dairi, Karo, Samosir and Simalungun are, respectively, 32, 56, 45 and 72 farmers

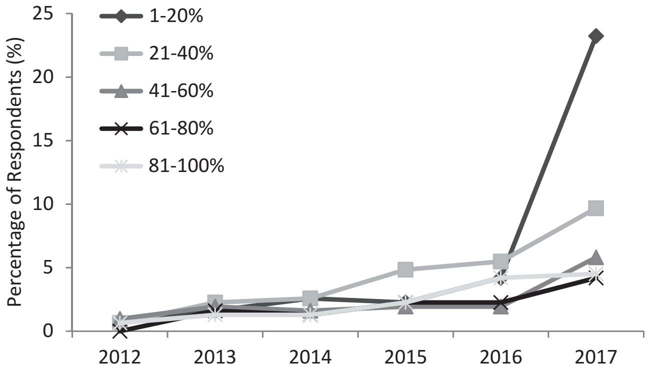


Fig. 5.11 Record of Coffee berry borer outbreaks in the study area during the periods of 2012–2017

Robusta and Liberica. Damages caused by this pest were mainly found on the apical parts of the coffee berry (Samsudin and Soesanthy 2012). The damages might cause yield decline as the young berries either dropped without ripening or showed lower quality of ripening berries.

Damage caused by coffee berry borer found to be linear with its outbreak level. In general, coffee berry borer destroyed about 80% of the total berries in the area. Farmers reported that from 2012 to 2017, the peak of coffee berry borer attacks was in 2017 (Fig. 5.11), where more than 65% of the farmers suffered crop damages with different damage levels. About 54% experienced a relatively low rate of damage (1–20%), 23% experienced medium damages (20–40%), and 10% experienced the worst damages (60–80%). The most common pest control for coffee berry borer in the study area, was using *Beauveria bassiana* and BROCAP trap. Unfortunately, only few farmers found these techniques to be effective.

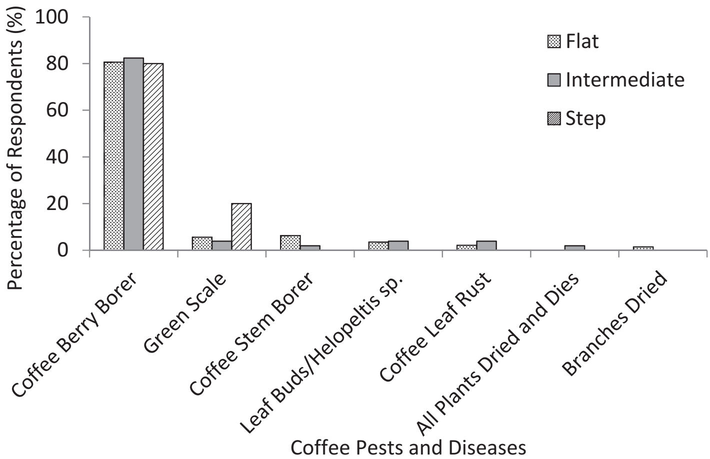


Fig. 5.12 Percentage of farmers experiencing various pests and diseases attacks by slopes

Table 5.6 Percentage of farmers experiencing various pests and diseases by cultivars type

	Cultivars					
Coffee pests and diseases	AS	KAS	KA	Aceh	KAN	KS
Coffee berry borer	90	100	62	100	100	75
Green scale	4	0	30	0	0	6
Coffee stem borer	4	0	8	0	0	6
Leaf buds/*Helopeltis* sp.	0	0	0	0	0	6
Coffee leaf rust	0	0	0	0	0	4
All plants dried and died	2	0	0	0	0	0
Branches dried	0	0	0	0	0	2

Note: *AS* Ateng Super, *KAS* Katinor Andung Sari, *KA* Katimor Ateng, *KAJ* Katimor Ateng Jaluk dan, *KS* Katimor Sigararutang

5.2.2.2 Relation of Pest and Diseases Attacks with Topography and Farming Practices

The analysis revealed no correlation between damage rate caused by coffee berry borer with plantation size, slopes, nor with coffee cultivars. Percentage of farmers experiencing coffee berry borer outbreaks on flat, intermediate and steep areas were 81%, 82% and 80% (Fig. 5.12), respectively. In general, there were no cultivars that were resistant to coffee berry borer. However, the survey revealed that KAS, KAN, AS and Aceh cultivars were relatively sensitive to coffee berry borer (Table 5.6). According to the farmers, KA variety showed the least sensitive to coffee berry borer, while KS was found to be the most vulnerable to all common pests and diseases (Table 5.6).

In the context of shade, monoculture farming without shade tent experienced the most damages from coffee berry borer (Table 5.7). Shade aims to create favourable condition for coffee plantation by reducing photorespiration and sunlight intensity. The growth of coffee plants needs a certain level of sunlight. Despite the attacks

Table 5.7 Distribution of pests and diseases attacks under different planting systems

	Farmers (%)		
Coffee pests and diseases	Unshaded monoculture	Shaded monoculture	Shaded polyculture
Coffee berry borer	85	79	80
Green scale	7	5	5
Coffee stem borer	1	0	9
Leaf buds/*Helopeltis* sp.	2	11	3
Coffee leaf rust	2	5	2
All plants dried and died	1	0.00	0
Branches dried	1	0.00	1

Table 5.8 Distribution of pests and diseases attacks under six different coffee productive ages

	Age (year)					
Coffee pests and diseases	<3	3–5	5–10	10–15	15–20	20–25
Coffee berry borer	100	80	79	90	100	0
Green scale	0	0	9	0	0	0
Coffee stem borer	0	7	3	0	0	0
Leaf buds/*Helopeltis* sp.	0	13	6	10	0	0
Coffee leaf rust	0	0	3	0	0	0
All plants dried and died	0	0	0	0	0	0
Branches dried	0	0	0	0	0	0

found on nearly all stages of productive periods, coffee plantations of 5–10 years of age were found to be the most vulnerable (Table 5.8).

5.3 Climate Variability and Its Impacts on Coffee Plantation

Two significant climatic variables that affect coffee are temperature and rainfall (ICC 2009). Both variables play critical roles in plant phenology, which eventually would determine the quality and quantity of coffee production (Haggar et al. 2011). Impacts of climate on coffee production vary among different cultivars and different growth stages. The following sections discuss the direct impacts of climate variables on coffee production, as well as indirect impacts related to the outbreaks of pests and diseases.

5.3.1 Climate Variability and Coffee Phenology

Rainfall distribution is crucial, because water is required during the vegetative to generative growth stages of coffee plants and the formation of floral primordium (Abdoellah 2016). Extreme climate conditions often hamper the development of coffee berries. Prolonged dry season and excessive rainfall would have detrimental effects on the flowering and conception processes (Susilo 2008). High rainfall

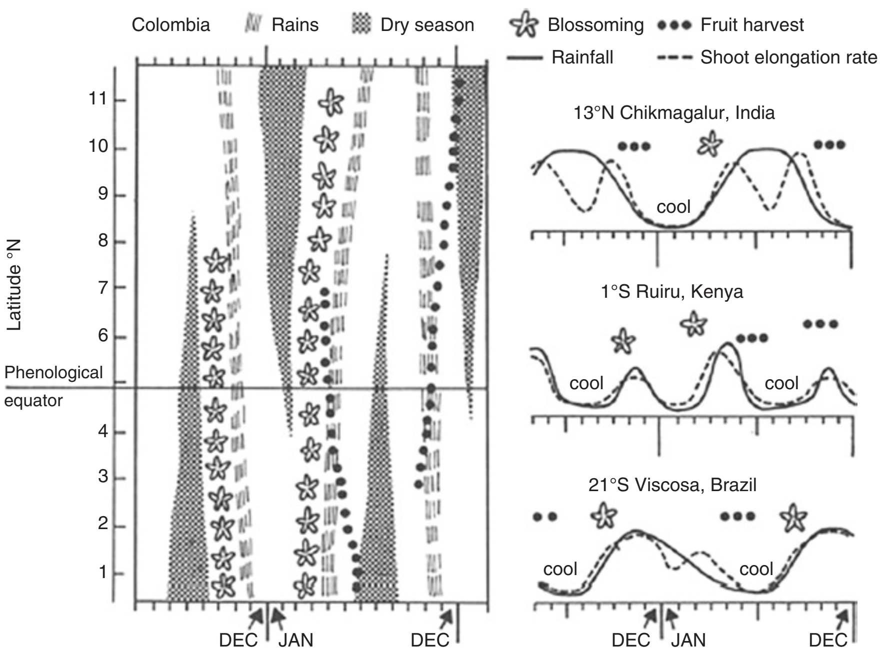


Fig. 5.13 Seasonal phenology of Arabica coffee. Times of blossoming and fruit harvesting at different latitudes (Left) and generalised seasonal changes in rainfall, shoot elongation rates and times of flowering and fruit harvesting in India, Kenya and Brazil (Cannel 1985)

would disrupt the pollination of flowers. The main driving factor for blooming is groundwater availability. Before the blooming season, flowers entered a period of dormancy for about 1–4 months and would remain dormant for an extended period under the condition of water deficit. Either the onset of rainy season or irrigation would support further development of coffee plants (Cannel 1985).

In coffee, the flowering periodicity is significantly determined by rainfall seasonality and length of seasons. Observations of coffee production centres worldwide have indicated that coffee flowering and harvesting stages are susceptible to rainfall pattern. The peak of coffee flowering and harvesting occurred twice a year in areas with bimodal rainfall seasonality near the equator (Fig. 5.13). Physiologically, the initiation and blooming of coffee flowers occur during the transition period from dry to rainy season and vice versa, because these processes were induced by changes in groundwater content. As indicated in the earlier paragraph, plants need a sufficient amount of water to leave the dormancy state and initiate blooming. However, excessive rainfall would inhibit this process, resulting in shrivelled flowers and back to the vegetative stage. Following the blooming season, plants would need at least three consecutive days without rain to start pollinating. Flowers would develop into fruits after pollination. High intensity of rainfall and short daylight during pollination would have resulted in fewer berries and abortion of flowers.

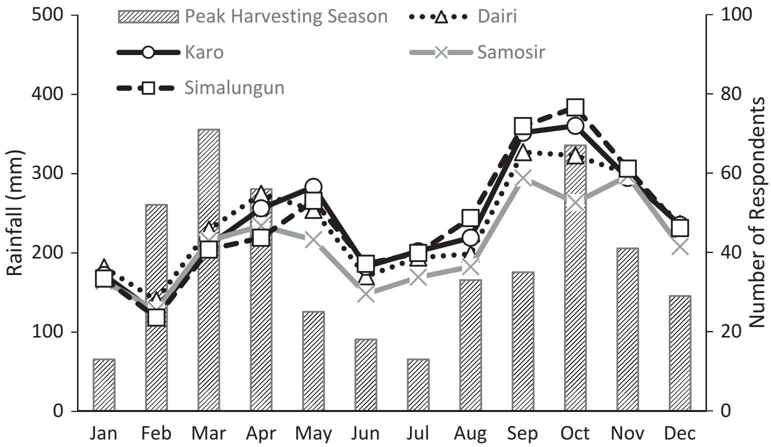


Fig. 5.14 Correlation between rainfall pattern and harvesting period of the coffee plantations in Toba areas

Once the berries are formed, it is essential to ensure an adequate amount of water to yield big and well-ripened berries. Lower rainfall might result in fewer yields due to the smaller berry size. The process from flowering to harvesting periods often takes about 9–12 months depending on the climatic conditions.

Toba is located near the equator, has bimodal rainfall seasonality, with the highest rainy season in April–May and September–October in line with the peak of coffee harvesting seasons (Fig. 5.14). Flower initiation, blooming, pollination, development and ripening of berries, followed the same pattern as the rainfall. In Toba area, flower initiation that occurs during the transition from dry to wet and wet to dry, coincided with the seasonal transition (June and December). Rainfall intensity during the transition periods played an essential role in determining the number of blooming and pollinated flowers. Erdiansyah et al. (2016) report that insufficient or irregular sunlight might create irregular fruit-set. Following the formation of fruit (berries), the plants would require further 6–7 months for ripening and development before harvesting (Fig. 5.15).

The development and growth of coffee berries require a high amount of water. Vegetative growth will be more vigorous under high intensity of rainfall, hence pruning should be scheduled more often. Super-selective pruning might necessarily be scheduled monthly in areas with higher intensity of rainfall, whereas selective pruning can only be scheduled once a year in drier areas (Yuliasmara et al. 2016), to ensure an optimum coffee-growing condition and to produce satisfying yields.

5.3.2 Climate Variability and Coffee Production

Rainfall and temperature are significant drivers for coffee production, where prolonged dry and rainy seasons will affect the flower development of coffee plants.

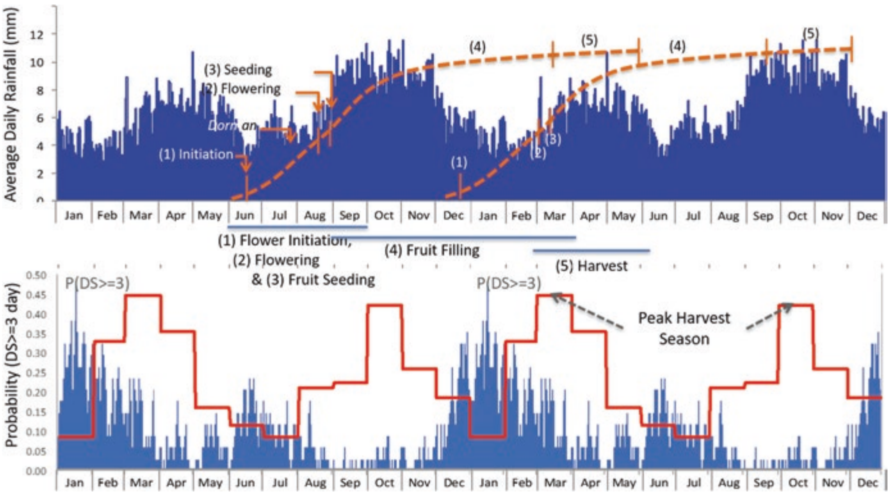


Fig. 5.15 Rainfall distribution along different phenological development of Arabica coffee (Top) and the probability of getting three consecutive days without rainfall (DS > =3 days) in Toba areas (Bottom)

Under very humid condition, the risk of shrivelling flower and fruit loss will increase (Nur 2000) and yields many empty berries (Soenarjo 1975).

Drought stress during prolonged dry season is often combined with high temperature and high solar radiation that could potentially harm coffee production (Pujiyanto 2016). Symptoms of lack of water or drought stress on coffee plantation begin with shrivelling, drying and falling of leaves. Water stress also causes stunted growth and detains buds' development and flowers' blooming, reducing production in the next year (Yahmadi 1973). Increase in temperature would affect plant metabolism such as flowering, photosynthesis and respiration that in general would affect the total coffee production (Syakir and Surmaini 2017).

Stress from rapidly increasing temperature is significant on Arabica coffee. Coffee plantation is usually located in high elevation areas, with a relatively low temperature in average. The analysis revealed that coffee growth is optimum in areas between 1300 and 1500 m MSL (Fig. 5.16). Toba coffee plantations are located within this elevation range.

Further analysis of the relationship between elevation and coffee production indicated that Super Ateng cultivar grows better at high altitudes and significantly produces higher yields on plantations located at 1600 m MSL. On the other hand, Katimor Sigararutang cultivar yields less on locations above 1400 m MSL (Fig. 5.17).

The analysis also found that coffee sensitivity to climatic conditions varied among different growth stages. The vegetative phase tends to be more sensitive to changes in temperature, while the generative phase was highly dependent on rainfall intensity and pattern. Table 5.9 summarises the impact of climate variability on coffee plantations. This information is necessary for further assessment of potential coping adaptation to climate change impacts.

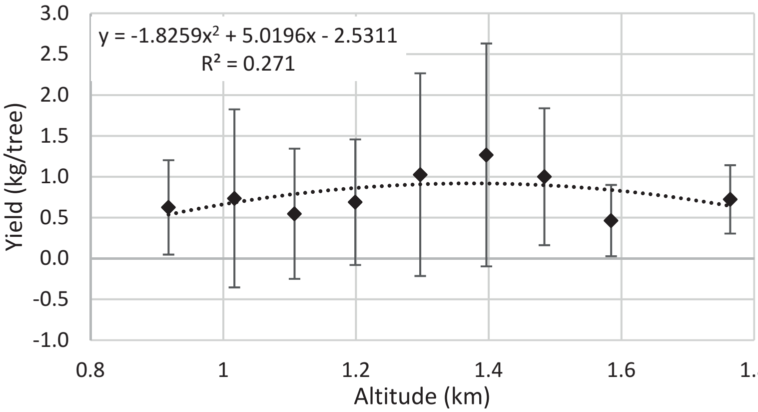


Fig. 5.16 Correlation between altitude and yield

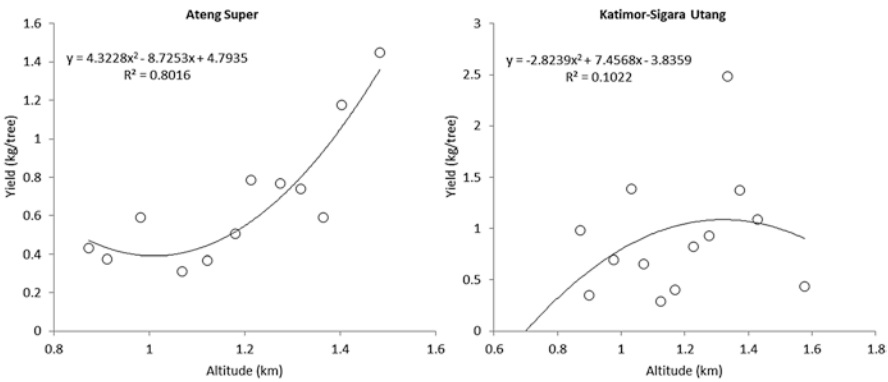


Fig. 5.17 Correlation of yields of AS and KS with location of plantations (altitude)

5.3.3 Climate Variability and Pest and Disease Occurrence

Pests and diseases have been identified as one of the critical factors in coffee production loss. Main pests and diseases include berry borer (coffee berry borer), nematode parasite (*Pratylenchus coffeae*) and leaf rust (Prastowo et al. 2010). Leaf rust is caused by *Hemileia vastatrix* Berk and Br. and nematode *Radopholus similis* (Cobb). Thorne also often harms Arabica coffee; berry borer *Hypothenemus hampei* Ferrari, *Pratylenchus coffeae* (Zimmermann) Filipjev and Schuurmans Stekhoven are commonly found to attack both Arabica and Robusta coffee. In general, common pests and diseases in Indonesia are dominated by nematode species (Wiryadiputra and Tran 2008).

Table 5.9 Summary of climate impacts on coffee production

Growth stage	Climate variable	Physiological impacts	Results	Source
Vegetative	$T > 25$ °C	Slower photosynthesis	Low production	Wilson (1985)
Vegetative (leaves development)	$T > 30$ °C (continuously)	Slower growth, yellow leaves, drying plants	Low production	Damatta and Ramalho (2006)
Generative (flowering)	Prolonged dry season	Flowers fall (direct)	Low production	Damatta and Ramalho (2006)
Generative (flowering)	High intensity of (extreme) rainfall	Flowers fall (direct)	Low production	Wintgens (2009)
Generative (seed filing/ germination)	$T > 23$ °C	Speedy growth and ripening that yield low-quality berries (indirect)	Low selling price	Damatta and Ramalho (2006)
Pest and disease	High temperature	Outbreaks	Low production	ICC (2009)

5.3.3.1 Coffee Berry Borer

Coffee berry borer is an indigenous African beetle and has been considered as the most dangerous pest for both Arabica and Robusta plants worldwide. Canephora (Robusta) coffee is the most susceptible to coffee berry borer (Lan and Wintgens 2009). Coffee berry borer has been spreading evenly in almost all coffee plantations in Indonesia including Papua, Sulawesi, Sumatra and Java (CABI 2000). The insect is predominantly found in lower altitude plantations. Berry borer has been a severe problem, not only in Indonesia but also in other coffee producing countries such as India and the Philippine. Loss of national production, both in quantity and quality, is significantly due to the attack from this pest (Sulistyowati et al. 1999; Samsudin and Soesanthy 2012).

Variation of coffee berry borer attacks depends on growth stages, land condition and cultivation system of the coffee plantations (Samsudin and Soesanthy 2012). Shades and light control may reduce the effect of coffee berry borer attack (Samsudin and Soesanthy 2012). As indicated in the earlier section, vulnerable period to coffee berry borer attack existed within the age of 5 to 10 years. The damage rate due to coffee berry borer in Toba has been categorised as high; some studies reported that production loss caused by the pest was about 25–49%. More than 60% of the Arabica coffee plantation in Toba had experienced coffee berry borer attacks within the last 10 years or equivalent to 50% of production lost (Rahayu and Wiryadiputra 2016).

The foremost climate variables that affected the level of coffee berry borer attack are temperature, rainfall and humidity. The cycle of coffee berry borer life is found to be longer at lower temperature and higher altitudes (Wiryadiputra 2012). Frequent rainfall throughout the year would also increase the possibility of coffee berry borer attacks, since under such climate, coffee flowering period is more frequent. Relative humidity and temperature also invite the spring of female insects.

Coffee Stem Borer

Coffee stem borers (*Xylotrechus quadripes* Chevrolat and *Acalolepta cervina* Hope) have been causing an extreme production loss of Arabica coffee in Thailand and China, although the effect was less harmful than berry borers (Lan and Wintgens 2009). Similarly, the climate variables influencing the intensity of stem borer are temperature and humidity. A humid environment is very favourable for the outbreaks of stem borer (Rahayu and Wiryadiputra 2016).

Green Scale

Coccus sp. is a soft green scale insect, which has also been a significant pest on Arabica and Robusta coffee plantation worldwide (Crowe 2009), although it was found to be more dominant on Arabica (Lan and Wintgens 2009). Green scales actively reproduced during the dry season, so it is necessary to wipe the eggs out before the dry season. Shading trees should also be maintained because the attacks are massive under thick set of shades.

Striped Mealybug

Striped mealybug, *Planococcus* spp., is found in almost all coffee plantations in the Philippine, Indonesia, Thailand, Malaysia, India and China (Lan and Wintgens 2009). The attack is worse during the dry season with intermittent rainfall. Random set and/or lack of shade trees worsen the damages caused by this pest. Shading should ideally be about 30% for Arabica coffee plantation and 20–25% for Robusta (Lan and Wintgens 2009).

5.3.3.2 Diseases

Microfungi, bacteria and few viruses have been the most common disease-causing organisms in a coffee plantation. The impacts on the different parts of the plant varied, from softening stem, damaged or even killed plants (Waller 1985). Climate change potentially worsens the impacts on coffee production. Increasing temperature has increased the impact of leaf rust on coffee planted in higher altitude. Lack of rainfall on low altitude plantation has caused water stress and an increasing case of Fusarium bark. On the other hand, wetter period can cause coffee berry disease (Waller et al. 2007). The following are some of the common diseases of coffee plantations in Indonesia.

Coffee Leaf Rust

Hemileia vastatrix Berk & Br is the cause of leaf rust. The fungus is originally from Africa and North America (Brown et al. 1995) and estimated to start spreading in Indonesia in 1876 as an airborne disease. Due to this disease, coffee plants usually shred leaves or even killed. Damage was about 58% or equivalent to 25% production loss (Amaria and Harni 2012). Arabica coffee is relatively more vulnerable to the disease compared to Robusta (Semangun 2000; Amaria and Harni 2012).

Leaf rust is commonly found in lower altitude plantations (<1500 m), because of the increased humidity and intensity of solar radiation (Rayner 1961; Waller et al. 2007). Therefore, Arabica planted in humid environment needs extra maintenance. Temperature is a critical climate variable in the spread of leaf rust (Waller et al. 2007).

Brown Eye Spot

Brown eye spot is caused by *Cercospora coffeicola* and *Mycosphaerella coffeicola* and commonly found in low altitude plantations, where the temperature is relatively higher. This disease is both airborne and waterborne through rainfall splash. The analysis has suggested that the current climatic condition is more favourable to the outbreaks of brown eye spots. Table 5.10 summarises the impacts of climate on pests and diseases.

5.3.3.3 Post-harvesting Infection Pests

Production and processing are susceptible processes to pests and diseases. Coffee processed in full wash, low moisture content, is relatively more resistant to pest and disease, while coffee produced or processed in humid tropical areas is more prone to pest or disease (Crowe 2009).

The major pest for stored coffee is beetle (*Araecerus fasciculatus* DeGeer). Such a case has been typical in pantropical areas. Maintaining humidity in a storage room or avoiding humid environment for storage may prevent the beans from the attack. Drying the beans under the sun can also kill this pest as the beetles will not be able to survive if the temperature is more than 37 °C (Crowe 2009).

5.4 Assessment of Historical and Future Climate

5.4.1 Historical Climate

The assessment of past climate was based on interpolated data of daily rainfall and monthly maximum and minimum temperatures. Daily rainfall was derived from CHIRPS (Climate Hazards Group InfraRed Precipitation with Station data) (Funk et al. 2014; Funk et al. 2015) which has been validated with observation data.

Toba is a part of the mountainous Bukit Barisan in the western part of Sumatra Island. Its location within equator and the topographical conditions have been the main factors determining the climatic condition. Toba has a bimodal equatorial rainfall, and the peak occurs in April/May and Sep/Oct (Fig. 5.18). Areas with an equatorial type of rainfall typically have high annual rainfalls. Analysis based on CHIRPS data (1981–2010) indicated that the annual rainfall in Toba area is high and ranges between 2250 and 3750 mm, with Samosir having the lowest annual rainfall and Simalungun with the highest annual rainfall (Fig. 5.19). The rainfall distribution pattern throughout the year is uniform in all study areas (Fig. 5.20). The lowest

Table 5.10 Summary of climate impacts on pests and diseases

Pest or disease	Climate variable	Attack level	Final impact	Region and source
Coffee berry borer (*Hypothenemus Hampei* [Ferr])	Optimum temperature 20–30 °C and humidity 90–95%	The attack is more common under humid environment. The warmer temperature may shorten the insect's life cycle so that it may increase the population	Berries are undeveloped, turned yellow, full of bores and eventually aborted	Southeast Asia, South America, Africa and China (Lan and Wintgens 2009), Indonesia (Susilo 2008; Samsudin and Soesanthy 2012; Wiryadiputra 2012)
Coffee twig borer (*Xylosandrus morigerus* and *Xylosandrus compactus*)	High humidity	The increase in temperature and humidity will increase the intensity of disease attack. The population rapidly increase in the rainy season but relatively lower in the dry season	Primary twig, seed and water shoots will shiver and die	Southeast Asia, Tropical Africa and India (Lan and Wintgens 2009), Indonesia (Rahayu and Wiryadiputra 2016)
Striped mealybug (*Ferrisia virgate*)	Humidity <70% and optimum temperature ± 30 °C	Population increase when the temperature increases	Flower buds, flowers and berries die	Southeast Asia and China (Lan and Wintgens 2009), Indonesia (Rahayu and Wiryadiputra 2016)
Coffee leaf rust (*Hemileia vastatrix*)	Humidity<70%	Increasing humidity will support the development of the disease and wind tends to spread mature spores	Yellow/ brown/black spots around the leaves and eventually leaves are falling	Nicaragua (Lan and Wintgens 2009; Brown et al. 1995; Waller 2007), Indonesia (Pratama and Aini 2016)
Brown eye spot (*Mycosphaerella coffeicola* or *Cercospora coffeicola*)	High humidity	High humidity during rainy season increases the risk to this disease	Brown to red necrosis on leaves and eventually leaves are falling	Indonesia (Pratama and Aini 2016)

(continued)

Table 5.10 (continued)

Pest or disease	Climate variable	Attack level	Final impact	Region and source
Pink diseases (*Corticium salmonicolor*) on stem, twig and berries	High humidity	The fungus spreads via wind and water/rainfall splash on humid and dark environment	Twigs are infected and killed	Indonesia (Pratama and Aini 2016)
Root diseases (*Phellinus noxius, Rosellinia bunodes* and *Rigidoporus microporus*)	Optimum temperature 25–30 °C, soil pH 3.5–7.5	Disease spreads faster in sandy areas with higher humidity	Infected the root and spread via the remaining damaged roots left under the surface	Indonesia (Wiryadiputra 2016), Kamerun (Lan and Wintgens 2009)

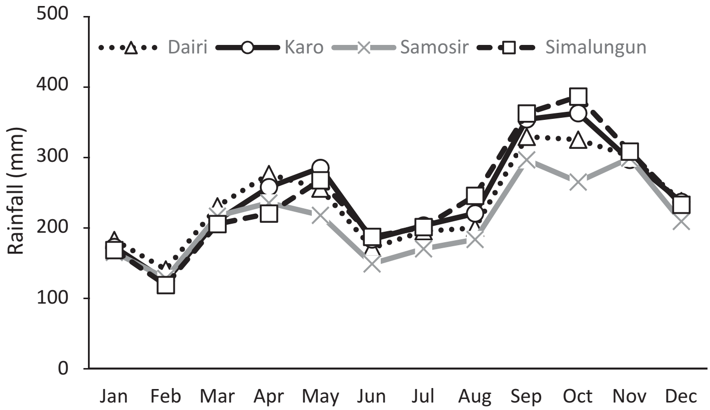


Fig. 5.18 Rainfall pattern of the four districts (study areas)

intensity of rainfall usually occurs in February, or June, July and August during the dry season or dry months. The monthly rainfall during the dry season, on an average is about 150 mm. Distribution of the dry months is in line with the rainfall pattern. The total number of dry months within a year is depicted in Fig. 5.21.

The temperatures in study areas were very much related to the topographical conditions. Higher topography experienced relatively lower temperature and vice versa. Minimum temperature ranges between 14 and 20 °C (Fig. 5.22), and maximum temperature ranges between 22 and 30 °C (Fig. 5.23). These are the ideal temperatures for coffee production. Therefore, Toba area is known as the coffee production centres. Dairi Highland is known as the best location to produce the best quality of coffee in Toba area followed by the Districs of Karo and Simalungun.

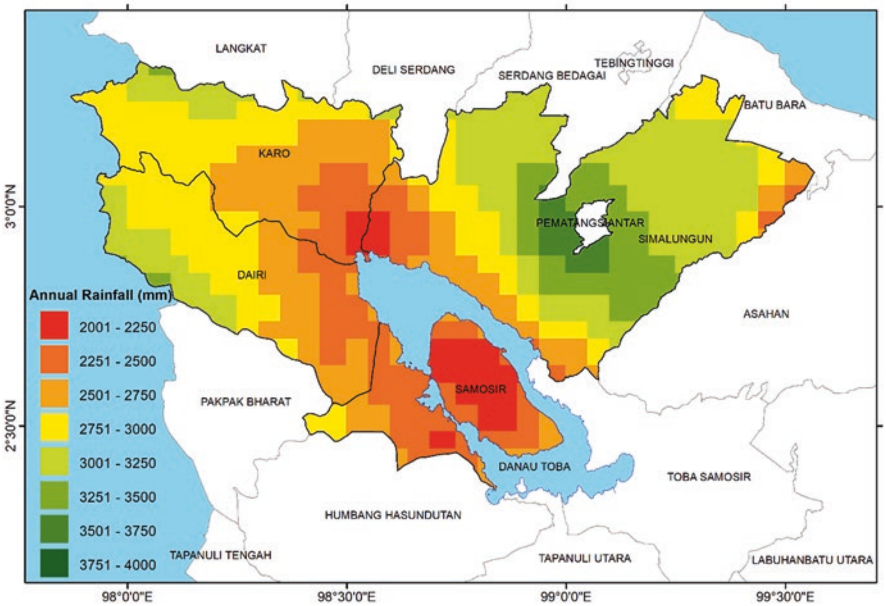


Fig. 5.19 Distribution of annual rainfall (mm) from 1981 to 2010. (Source: CHIRPS data (http://chg.geog.ucsb.edu/data/chirps/) validated with observation data)

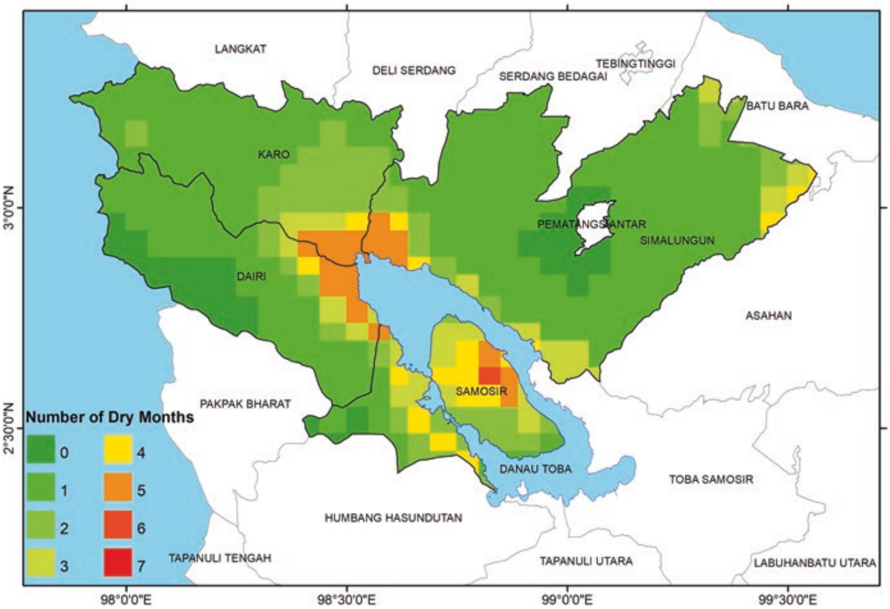


Fig. 5.20 Distribution of number of dry months in Toba area

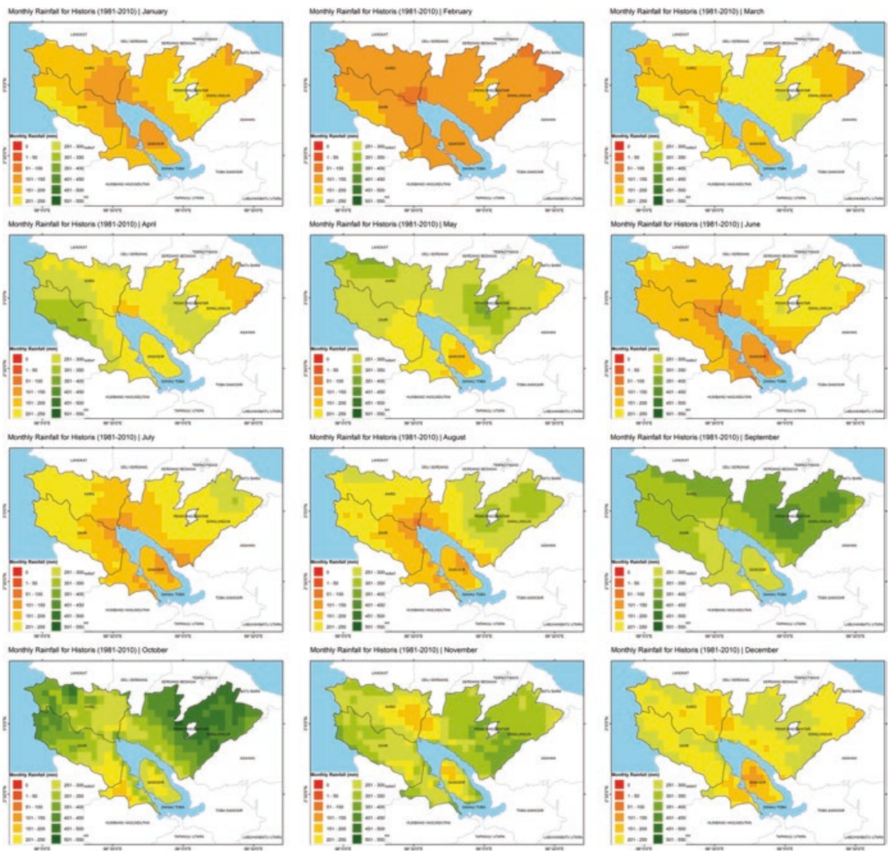


Fig. 5.21 The distribution pattern of monthly rainfall (mm) from 1981 to 2010. (Source: CHIRPS data (http://chg.geog.ucsb.edu/data/chirps/) validated with observation data)

5.4.2 Climate Projection

The IPCC Fifth Assessment Report highlighted that climate change has occurred due to increasing global temperature as the result of the rapid increase of GHG concentration in the atmosphere due to anthropogenic activities. The highest recorded concentration of CO_2 was in June 2013 with more than 400 ppm and has increased the global temperature by 0.85 °C than the pre-industrial era. If the current emission rate continues, the CO_2 concentration in the atmosphere by 2100 will be more than 1000 ppm and would increase the global temperature by 4–5 °C, higher than the pre-industrial era (IPCC 2014). Once this is happening, the impacts of climate change would be very devastating and no longer manageable. Losses due to extreme climate events are high, and costs for adaptation would be super expensive. Therefore, it is necessary to push the emission level to the lowest possible, so the future impacts would remain manageable and at low costs. Better mitigation actions would be necessary to minimise the need for adaptation.

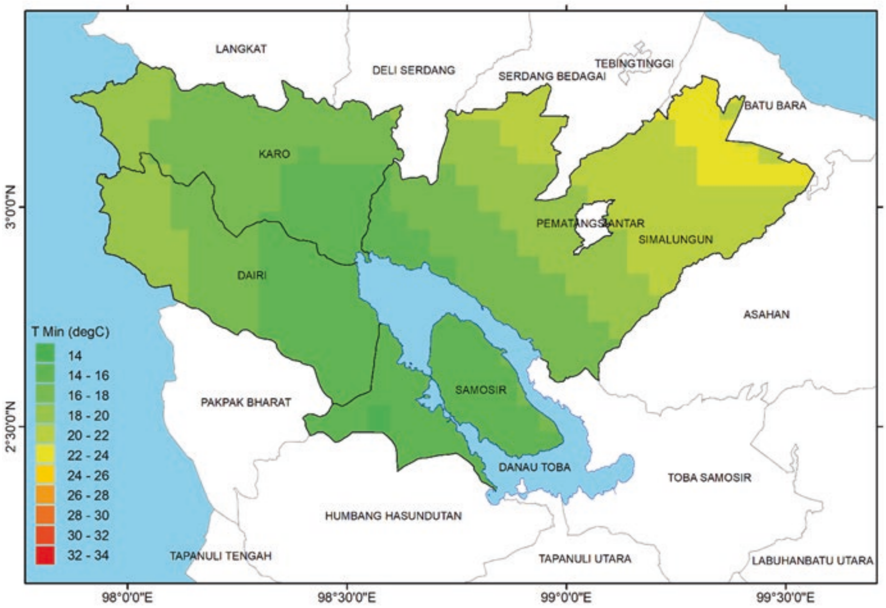


Fig. 5.22 Distribution of minimum temperature from 1981 to 2010. (Source: CRU (http://www.cru.uea.ac.uk/data) validated with observation data)

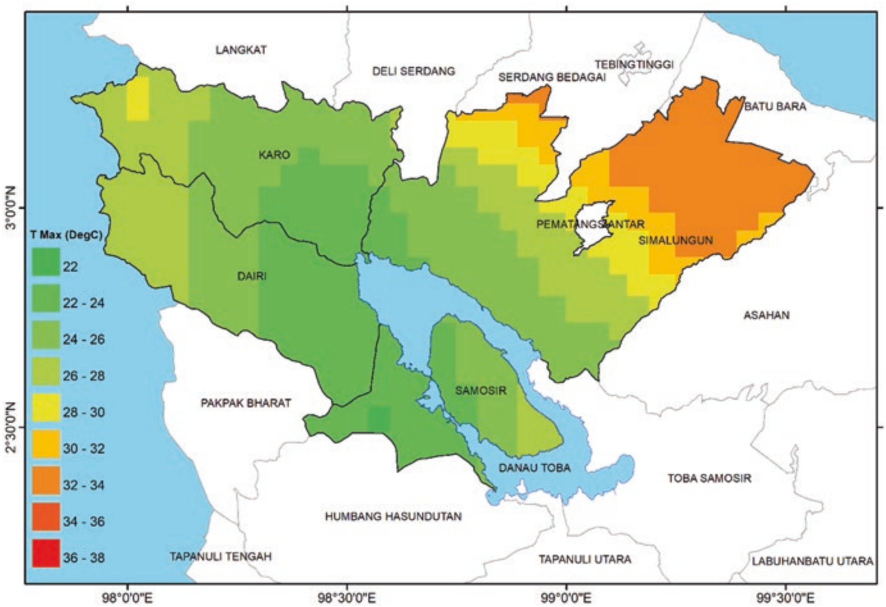


Fig. 5.23 Distribution of maximum temperature from 1981 to 2010. (Source: CRU (http://www.cru.uea.ac.uk/data) and validated with observation data)

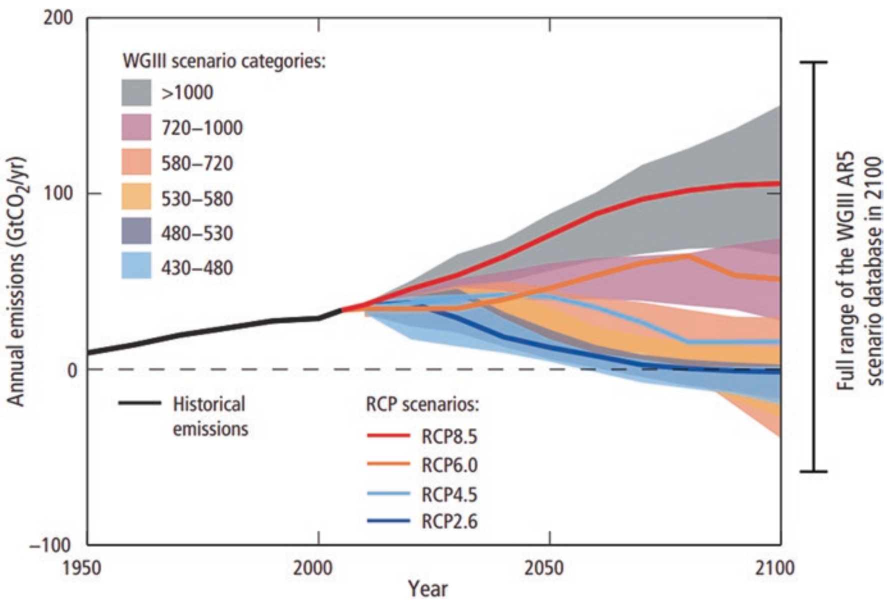


Fig. 5.24 Projection of annual CO_2 emissions under four different scenarios (IPCC 2014)

Maintaining the global temperature increase below 2.0 °C or even 1.5 °C will ensure that the impacts of climate change remain at a manageable level (IPCC 2014). This has been set as the global target and is indicated in the international climate policies. IPCC (2014) has projected future emissions under four scenarios based on population growth, economic activities, lifestyle, use of fossil fuels, land use, technological development and climate policies. RCP2.6 is known as the most optimistic scenario with the most achievable global target and the mitigation plans are effectively implemented. RCP4.5 and RCP6.0 have medium to high mitigation scenarios, the emissions are projected to remain high and failure to achieve the global target. The last scenario – RCP8.5, is the most pessimistic scenario with the highest emission projection. The RCP6.0 and 8.5 scenarios may occur without any mitigation actions (Fig. 5.24).

Under the RCP2.6 scenario, the emission would be significantly reduced before 2030 and come to a 0 level starting from the year 2070 (Fig. 5.24). This means that fossil fuel will be removed from the lists of energy sources, and LULUCF effectively plays its essential role in carbon sequestration towards negative emissions scheme. Countries under the convention are only able to set an agreement to follow RCP4.5 scenario, a stabilisation scenario that allows the emission to peak in 2040 and then decline. The decline is not extremely pushed to zero as in the case for RCP2.6 scenario. Under the RCP4.5 scenario, CO_2 concentration in 2100 is projected to be around 550 ppm – higher than the global target. This assessment only follows the emission projection under scenarios RCP4.5 and RCP 8.5 (Moss et al. 2010). Climate change under both scenarios is simulated using the regional climate model RegCM4. Scheme and simulation process in RegCM4 are explained in Faqih et al. (2016). The model has a spatial resolution of 20 × 20 km and runs ICBC data – the outputs of HadGEM2-ES global climate model (Collins et al. 2011; Martin et al. 2011). Outputs of RegCM4.4 are validated following the procedures from Jadmiko et al. (2017).

Climate change projection is specifically centred on temperature and rainfall, because both variables are the major determinant variables for plant growth. The projection period is split into (i) 2011–2040, (ii) 2041–2070 and (iii) 2071–2099. The analysis was based on general delta method and multiplier (e.g., Lenderink et al. 2007). Delta method is used to validate the projection of temperature from climate model ($X_{mp,i}$) based on the deviation of the model (U_{mb}) from observation data (U_{ob}) during the historical period of 1981–2010. The corrected temperature projection of year – i ($X_{cor,i}$) is explained below:

$$X_{cor,I} = X_{mp,i} + \left(U_{ob} - U_{mb}\right) \quad (5.1)$$

Correction method for rainfall data is as follows:

$$X_{cor,I} = X_{mp,I} * \left(U_{ob} / U_{mb}\right) \quad (5.2)$$

A more detailed description of the methodology for climate projection is available in the Indonesia Third National Communication Report (Faqih et al. 2016).

The analysis found that the minimum temperature in Toba area under the RCP8.5 scenario would increase about 2.0 °C by 2050, while under RCP4.5, the increase would only be about 1.5 °C. Later in 2099, the projected temperature increase under RCP8.5 scenario is 4.5 °C and under RCP4.5 scenario is 2 °C (Fig. 5.25). The increase varies among different areas, but in general, areas with lower altitude tend to experience higher increases of minimum temperature (Fig. 5.26). The maximum temperature is projected to increase at about 2.0 °C by 2050 under the RCP4.5 scenario and about 2.5 °C under the RCP8.5 scenario. Further in 2099, the maximum temperature is projected to increase for both RCP4.5 and 8.5 scenarios by 3 °C and 5 °C, respectively (Fig. 5.27). Similar to the minimum temperature, the increases are also relatively higher in areas of lower altitude (Fig. 5.28). In general, the RCP8.5 scenario suggested a more significant increase of temperature than RCP4.5 scenario for the post mid-twenty-first century.

Another key climate factor in coffee production is rainfall. The future rainfall in Toba area is projected to be 10–15% lower than the current condition. However, from 2071 to 2099, under the RCP8.5 scenario, it is projected to decrease by about 30%, especially within the western part of Dairi. This is equivalent to the national projection where rainfall throughout Indonesia is on an average, decreased 30% from the current condition. In contrast, Samosir area is projected to experience a 5% increase in rainfall. Analysis of the rainfall distribution in the Toba area indicated that in general, the rainfall intensity is decreasing. Changes in rainfall varied among different locations and the variations were high (Fig. 5.29). In general, the western and eastern parts of Lake Toba tend to experience lower rainfall while the northern part experienced slightly higher rainfall than the current levels (Fig. 5.30). The extreme level of rainfall decrease is projected to occur in the western part of Toba in 2099 under the RCP8.5 scenario (Fig. 5.30).

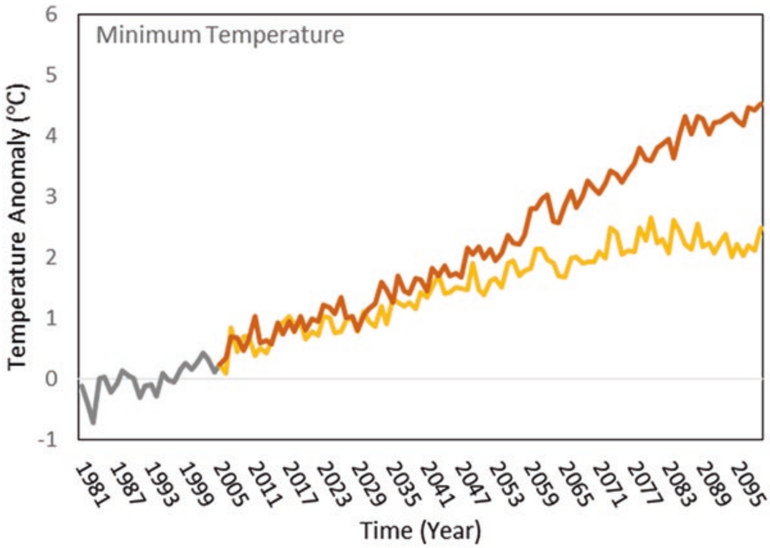


Fig. 5.25 The increasing trend of minimum temperature in Toba area (Yellow lines-RCP4.5 Scenario; Brown lines-RCP8.5 Scenario)

Projection of lower rainfall will have an impact on the length of dry season/months. In general, the total length of dry months in Toba area from 2011 to 2040 is expected to be 1–2 months longer than the existing condition (1981–2010). The prolonged dry season would be worsened by 2071–2099, especially under the RCP8.5 scenario (Fig. 5.31). Longer season is observed to be significant in the north-western part of Lake Toba.

5.5 Climate Change Impacts on Coffee Plantation

Climate change is projected to have significant impacts on yields, occurrence of outbreaks, growth and development of coffee plantation including changes in land suitability for coffee plantation. As stated in the earlier sections of this chapter, Arabica coffee is ideally grown at low-temperature areas, which is often found at an elevation of 800 m MSL. Nevertheless, under the changing climate, areas known best for growing coffee would be shifted upwards. This study focused on climate change impacts on (i) shifting of coffee-growing areas, (ii) growth and development of coffee plantation and (iii) outbreaks of major coffee pests, i.e. coffee berry borer or stem borer.

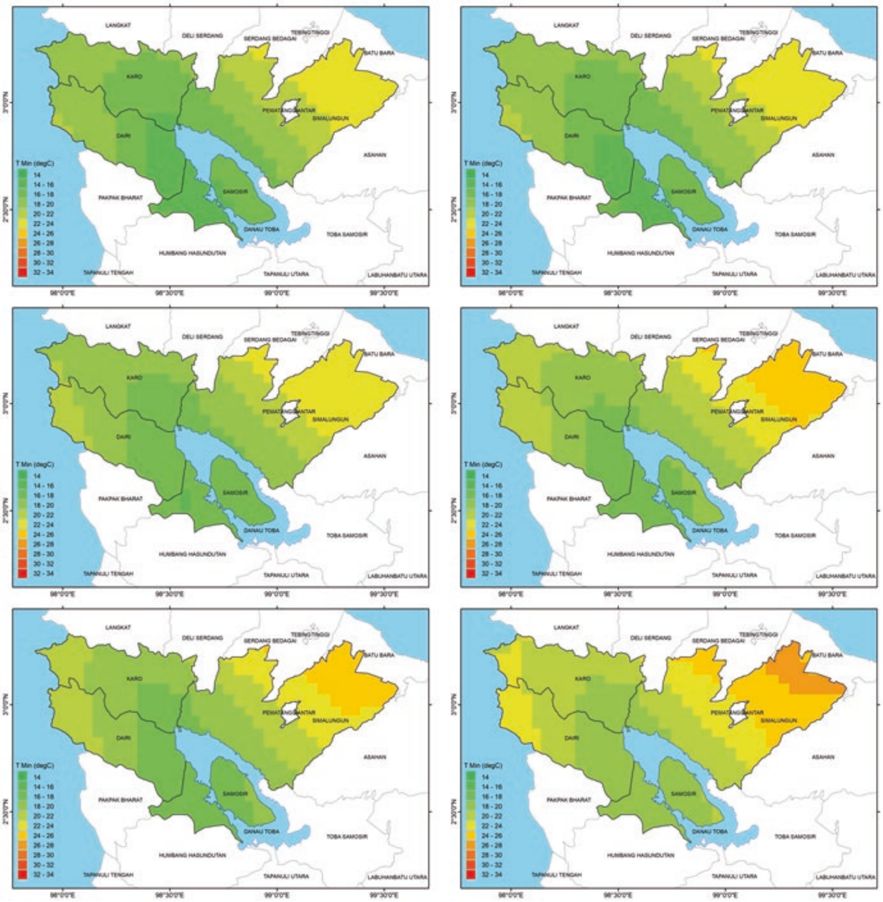


Fig. 5.26 Projection of minimum temperature in Toba area. (Based on RegCM4 simulation)

5.5.1 Method of Analysis

5.5.1.1 Climate Suitability

Analysis of climate suitability followed the criteria by Descroix and Snoeck (2012). Climate factors included in the analysis are minimum and maximum temperatures, annual rainfall and length of dry months. There are three procedures to follow for the analysis. The first procedure is the identification of suitable classes based on the correlation between each climate variable and production (survey); second, climate suitability of the area is set for each climate variable, based on suitability classes and climate suitability index (CSI); and, third, to determine the climate suitability class of the area, expressed as Area Climate Suitability Index (ACSI) based on CSI.

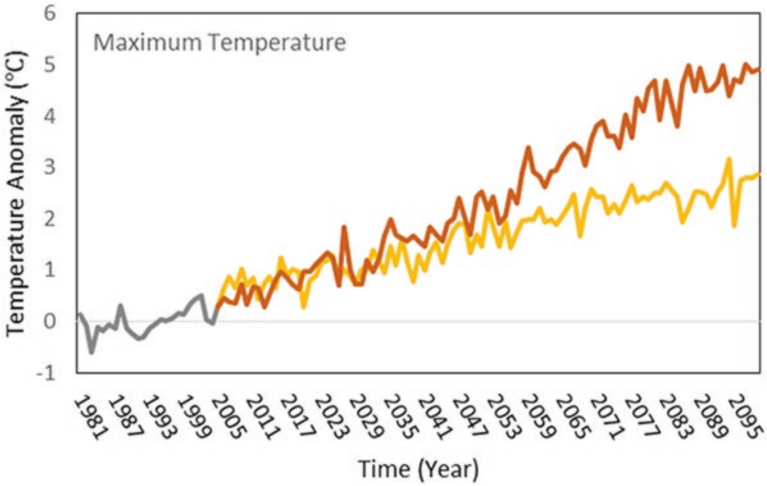


Fig. 5.27 The increasing trend of maximum temperature in Toba area (Yellow lines-RCP4.5 Scenario; Brown lines-RCP8.5 Scenario)

Climate suitability classes are determined based on the regression analysis between climate condition and actual yields from survey data. Historical climate data was interpolated from the satellite rainfall estimates. Daily rainfall data was obtained via CHIRPS (http://chg.geog.ucsb.edu/data/chirps/) and validated with observational data. Rainfall data was used to identify the annual rainfall and the number of dry months, which according to BMKG refers to the number of months with rainfall less than 150 mm (http://www.bmkg.go.id/iklim/prakiraan-musim.bmkg). Climate suitability classes (S) in this study are categorised into the following: (i) very suitable (Score = 1); (ii) suitable (Score = 2) and (iii) not suitable (Score = 3).

Climate suitability index (CSI) is calculated based on the following equation:

$$\mathrm{CSI} = 1/n * S\left(n_i * S_i\right) \tag{5.3}$$

where n is the number of recorded years, n_i is the number of years with certain climatic condition and S_i is the suitability class i, $i = 1, 2$ and 3. The CSI value of each climate variable is calculated for both historical and three future periods (2011–2040, 2041–2070 and 2071–2099).

Area Climate Suitability Index (ACSI) is mainly determined by CSI, using the equation below:

$$\mathrm{ACSI} = Sw_j * CSI_j \tag{5.4}$$

where w_j is a weight for CSI climate variable j. Weight is assigned to each climate variable based on its contribution in explaining the variance of coffee production. ACSI values range from 1 to 3. Based on ACSI, area suitability is categorised into (i) very suitable with two subcategories, (ii) suitable with three subcategories, (iii)

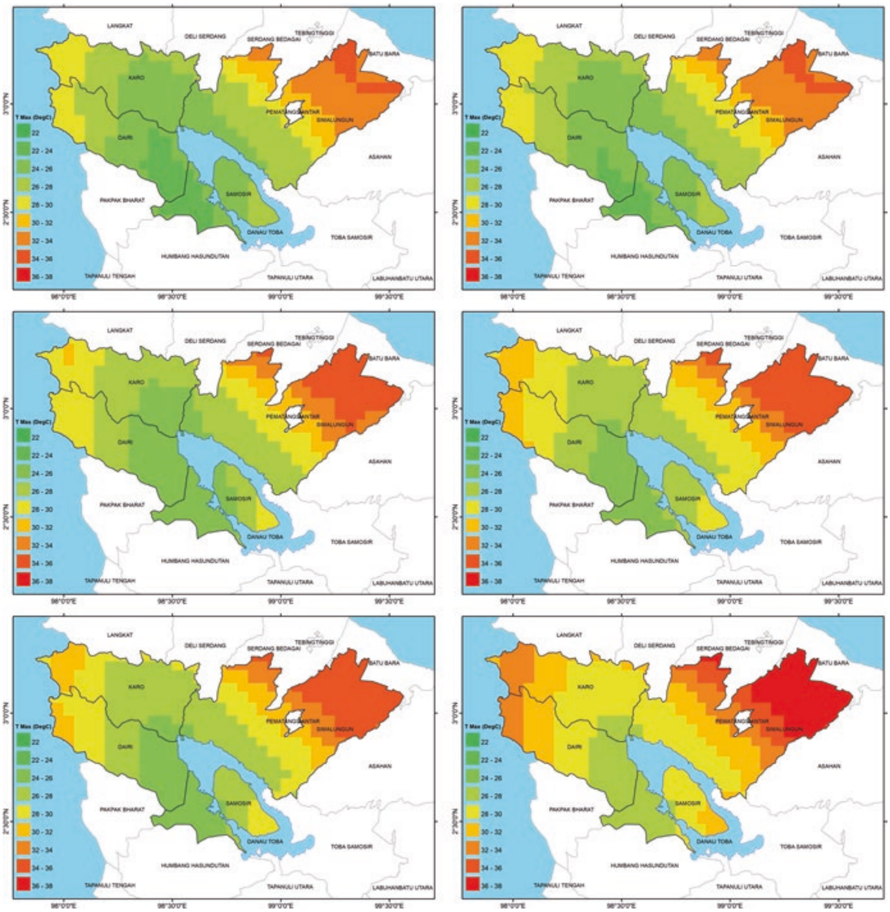


Fig. 5.28 Projection of maximum temperature in Toba area. (Based on RegCM4 simulation)

slightly suitable and (iv) not suitable. A more detailed description is given in Table 5.11. Area suitability is then mapped and calculated to obtain the total area for each category.

5.5.1.2 Plant's Growth and Development

Climate variability impacts on the growth and development of coffee plants were assessed using a qualitative approach to obtain the correlation between plants' phenological characters and climate condition. Impacts on yields are calculated using regression analysis as follows:

$$Y(\text{yield}) = f(\text{Rainfall, Number of Dry Month}, T_{\min}, T_{\max}) \quad (5.5)$$

Yield is measured from the average yield per elevation category (850–1650 m MSL with intervals of 50 m). Regression analysis was weighted because coffee

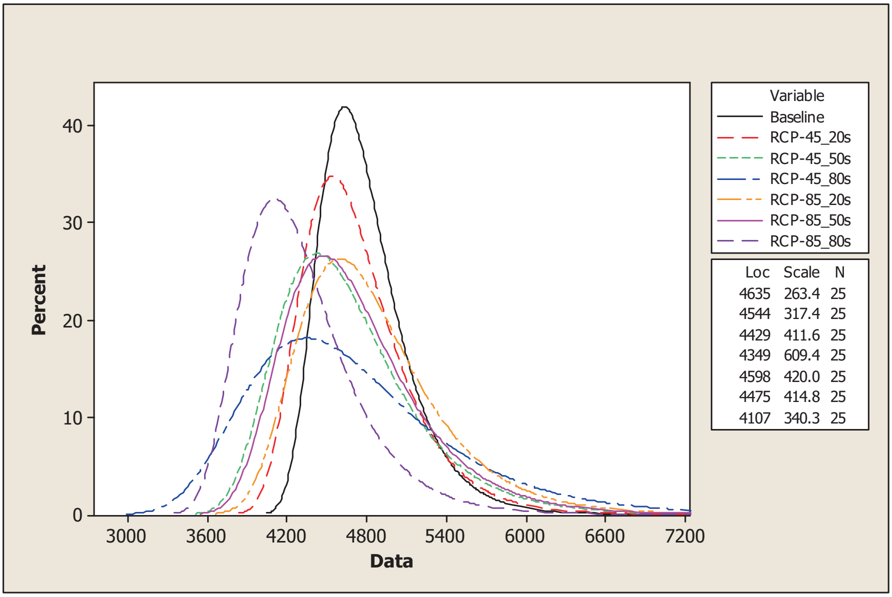


Fig. 5.29 Distribution of annual rainfall pattern

yields varied with elevations. Weight for yield average is $1/\sigma^2$ where σ^2 is yield variance. The future yield average was also estimated using the same equation as climate projection in all grids within the area. It is assumed that the correlation between the present and future yields and climate variables remained unchanged (excluding technological development in coffee cultivation). The contribution of each climate variable on yields would give CSI and ACSI.

5.5.1.3 The Level of Coffee Berry Borer Attack

Climate change impacts on the development of insects populations are approached by means of life table theory or the so-called demographic statistics. Mortality and survival of insect populations are systematically described in the demographic statistics. These are the necessary basic information to understand the changes in the density and growth rate of an insect population and the correlation with climate change.

Insects demographic statistics is defined as the quantitative analysis of insect population life cycle, the ability of female insects to produce eggs and the population growth trend (Zeng et al. 1993). Data on survival rate and egg laying ability are sorted in a life table (Table 5.12). The biological variables observed for the development of demographic statistics include (1) growth of eggs from nymph to imago, (2) growth from first to the fourth instar, (3) period of development from the fourth nymph to pupae, (4) growth from pupae to imago, (5) life as imago, (6) pre-egg laying period and (7) number of eggs laid.

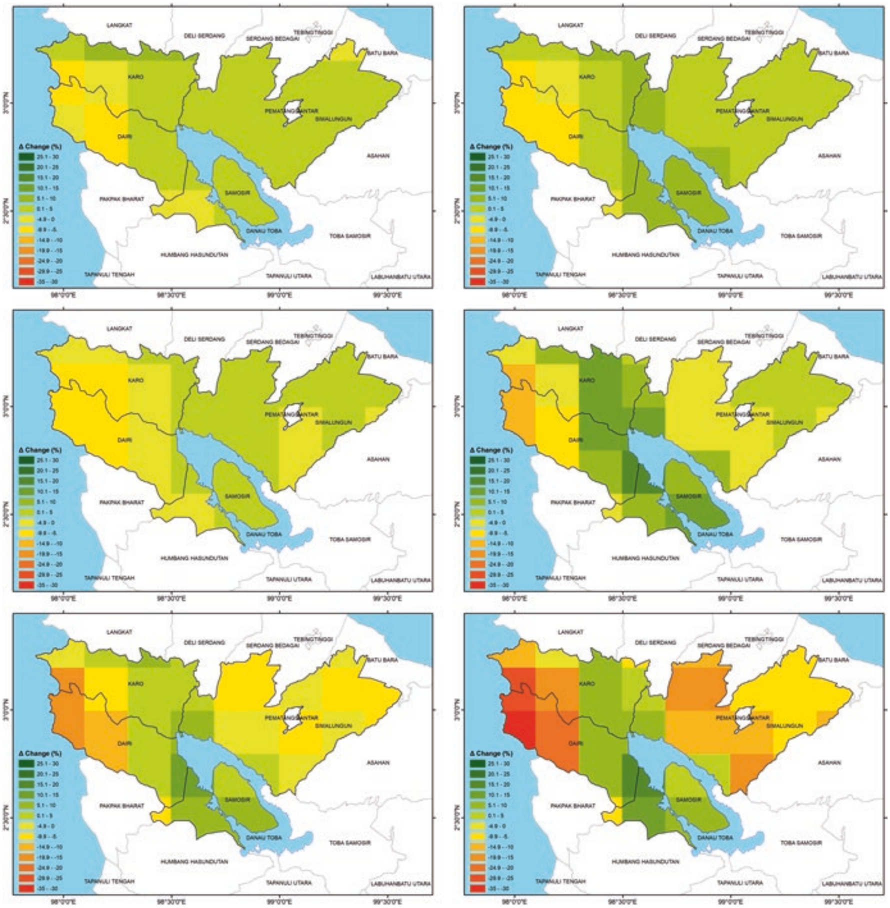


Fig. 5.30 Distribution of rainfall changes in Toba area based on RegCM4 analysis

Population growth is highly dependent on female insects' survival rate (l_x) and fertility (m_x) known as the net reproduction rate. Total female pupae born over an average number of female insects parent in the population is defined as reproduction rate (R_0) – meaning that there is a set of female insects replacing the earlier female generation in the population. A stable population is $R_0 = 0$; if $R_0 > 1$, the population tends to increase, and if $R_0 < 1$, the population tends to decrease. Once R_0 is identified, the length of a generation (T), intrinsic growth rate (r) and doubling time (DT) can be calculated. In general, DT describes the growth of population based on demographic statistics.

The major climate factor in insect demographic is temperature (Bale et al. 2002; Kiritani 2006, 2007, 2013; Gomi et al. 2007; Dingemanse and Kalkman 2008; Jaramillo et al. 2009). Research in a greenhouse indicated that temperature played

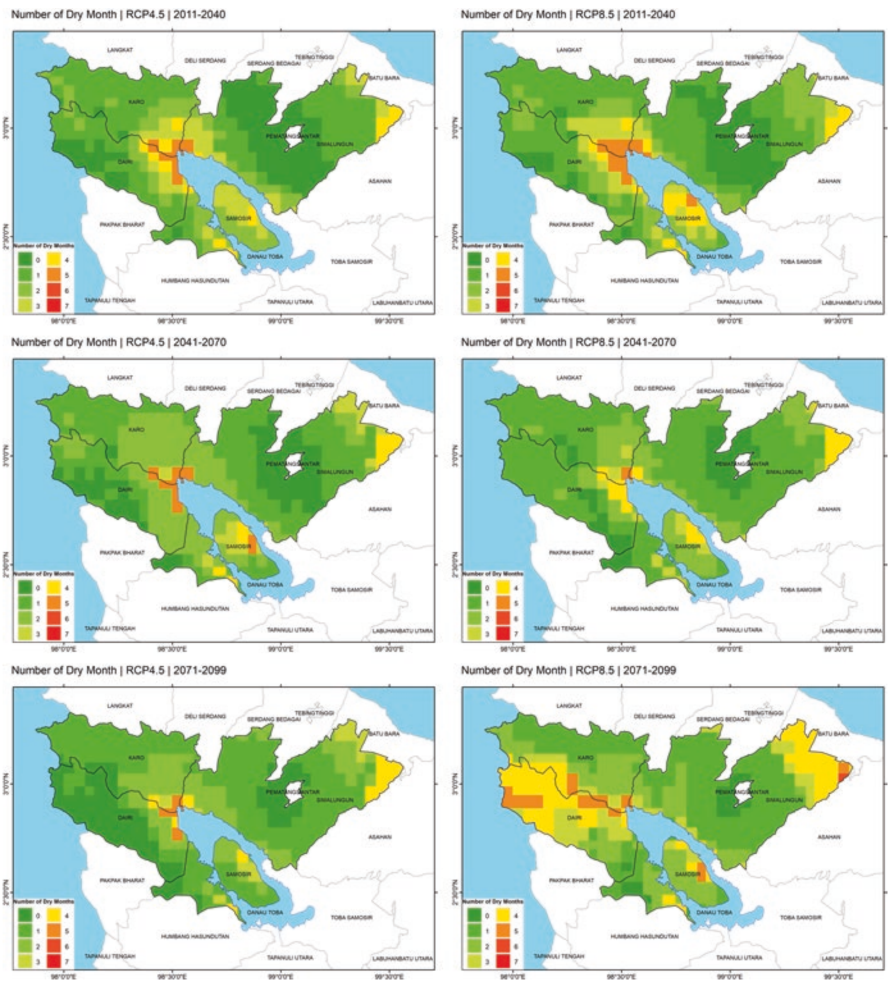


Fig. 5.31 Distribution of prolonged dry months projection in Toba area based on RegCM4 analysis

an important role in the population doubling time (DT). However, the correlation is nonlinear and follows the equation below (Fig. 5.32):

$$\mathrm{DT} = 134 - 9.93 * t + 0.191 * t^2 \tag{5.6}$$

This equation is relevant to calculate the number of days required by coffee berry borer in Toba to double.

The impact of changes in temperature on DT is expressed as the coffee berry borer population doubling index (PDI):

$$\mathrm{PDI} = \mathrm{DT}(t) / \mathrm{DT}(t_0) \tag{5.7}$$

Table 5.11 Area climate suitability classes for coffee plantations in Toba area

Area Climate Suitability Index (ACSI)	Sub-category	ACSI range
Very suitable (VS)	VS1	1.0–1.2
	VS2	1.2–1.4
Suitable (S)	S1	1.4–1.6
	S2	1.6–1.8
	S3	1.8–2.0
Moderately suitable (MS)	MS	2.0–2.2
Unsuitable (NS)	NS	>2.2

Table 5.12 Parameters in demographic statistics

Parameter	Equation
Net reproduction rate (R_0)	$R_0 = \Sigma l_x m_x$
Intrinsic growth rate (r)	$r = \ln R_0/T$
Average of life (T)	$T = \Sigma x l_x m_x/\Sigma l_x m_x$
Population multiplication (DT)	DT = ln (2)/r

Source: Birch (1948)

x = Cohort age class(day i); lx = Proportion of an insect living at age x; mx = Specific egg laying ability of insect in age class x

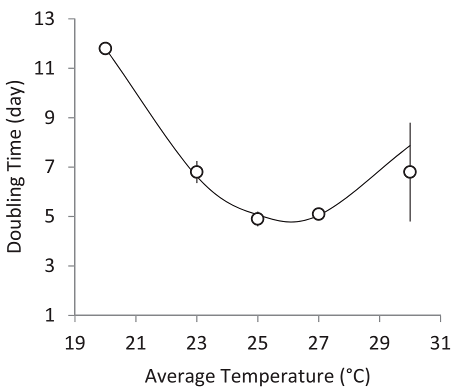


Fig. 5.32 Correlation between doubling time (DT) and temperature. (Adapted from Jaramillo et al. 2009)

where t_0 is the shortest coffee berry borer doubling time in Toba area which is set as the *base time*. DT (t_0) in Toba is 4.94 days. If PDI = 1, then DT(t) would be 4.94 days; if PDI = 2, then DT(t) would be twice longer than the base time or 9.87 days.

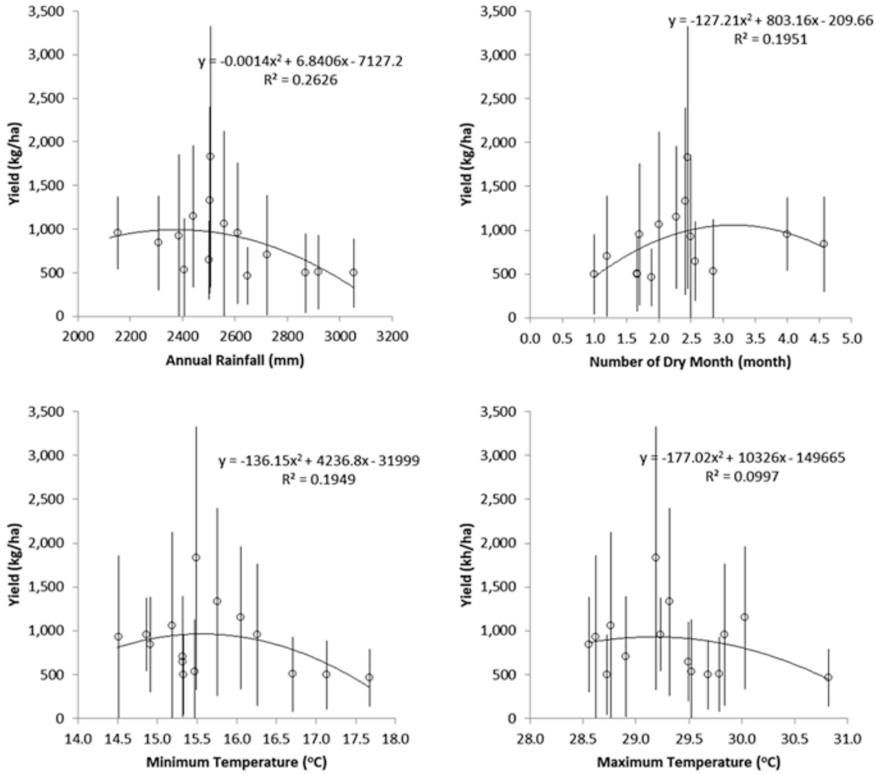


Fig. 5.33 Relationship between climate and coffee yield

5.5.2 Impacts on Coffee Plantation

5.5.2.1 Climate Suitability for Coffee Plantation Area

Regression analysis for each climate factor and coffee yield showed a nonlinear relationship (Fig. 5.33). Yield was relatively lower, if the annual rainfall is at extreme low (less than 1650 mm) or extreme high (more than 3200 mm). The highest yield is produced in areas with annual rainfall ranging from 2050 to 2840 mm (Fig. 5.33). Yield is found to be at a moderate level on areas with annual rainfall of 1650–2050 mm or 2840–3200 mm.

Another variable is the number of dry months, with an optimum range of 2.5–3.8 months. Shorter or longer dry months than the optimum range usually would result in less yield. Both low and high extremes temperatures are also unfavourable for coffee production (Fig. 5.33). Regression equation used to identify the suitability class is listed in Table 5.13. Results of the analysis were in line with existing literature that concluded Arabica coffee needed an annual rainfall of about 1250–3000 mm and showed optimum growth at 1700 mm. The ideal altitude is between 800 and 1500 m above sea level with temperature about 17 °C–23 °C. Unlike Robusta, Arabica coffee is less sensitive to the length of dry months and can survive up to 5 months.

Table 5.13 Climate suitability area for coffee plantations in Toba

	Climate suitability class (S)		
	Very suitable	Suitable	Not suitable
Climate variables	Score = 1	Score = 2	Score = 3
T_{max} (°C)	28.5–30.0	27.5–28.5 and 30.0–31.0	<27.5 and >31.0
T_{min} (°C)	14.5–16.5	13.5–14.5 and 16.5–17,5	<13.5 and >17.5
Rainfall (mm)	2050–2840	1650–2050 and 2840–3200	<1650 and >3200
Number of dry month (month)	2.5–3.8	1.0–2.5 and 3.8–5.5	<2.5 and >5.5

Table 5.14 Weight of climate suitability index (CSI)

Climate variable	Weight
Minimum temperature	0.48
Maximum temperature	0.20
Rainfall	0.30
No. dry months	0.02

Table 5.15 Total very suitable coffee plantations areas (ha) under current and future climates

		2011–2040	2041–2070	2071–2099
Elevation (m asl)	Current	RCP4.5		
700–1500	311,124	221,880	101,331	46,431
1500–2500	51,827	74,622	91,718	90,757
		RCP8.5		
700–1500	311,124	202,314	52,754	779
1500–2500	51,827	77,196	88,420	54,645

CSI is then calculated using the climate suitability class criteria (Table 5.13) for the periods of 2011–2040, 2041–2070 and 2071–2999 to obtain suitability classes of 1, 2 or 3. The analysis indicated that CSI for each climate variable is higher, meaning that climate suitability is getting less suitable. CSI determines ACSI, and in calculating the ACSI, CSI is given weights as shown in Table 5.14.

Based on the analysis, it was found that in the future, the total areas of coffee plantations located at elevations of 700–1500 m MSL that were classified as very suitable, would experience declines (Table 5.15). Very suitable areas are shifting towards higher elevations (Fig. 5.34). Nevertheless, higher elevation areas are mostly categorised as protected land. Total areas and distributions of climate suitability classes under the current and future climate are presented in Fig. 5.35.

5.5.2.2 Plant Growth and Development Index

In general, the climate change in Lake Toba was indicated by increase in temperature (Fig. 5.26 and Fig. 5.28) and changes in rainfall (Fig. 5.30). The future

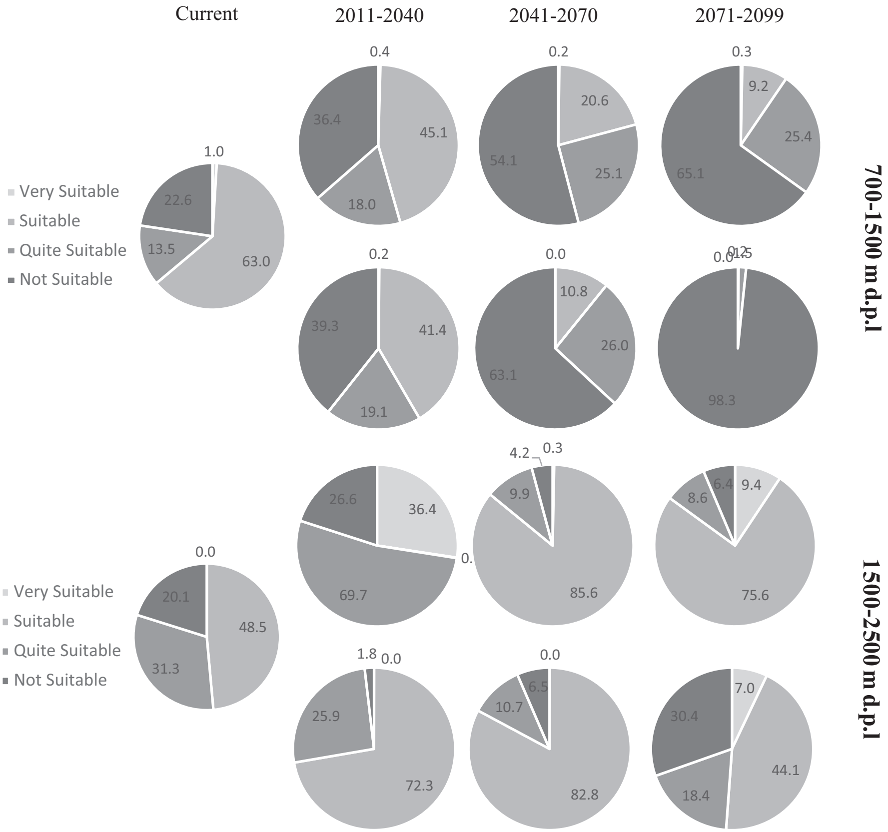


Fig. 5.34 Percentage of area of climate suitability index

occurrence of extreme low or high temperatures were projected to be more frequent and more prolonged. Change of climate as well as the impacts varied among locations. A significant increase in rainfall during the rainy season and prolonged dry season would influence the coffee phenological development. Climate change tends to shift the peaks of flowering and harvesting seasons in Toba. The high intensity of rainfall would reduce yields because it might cause the flowers to fall and increase the risks to grow vegetative branches more than the productive branches.

Analysis of the correlation between yields and climate is represented well by temperature and rainfall. The equation is as follows:

$$Y\left(\text{kg}/\text{ha}\right) = -28{,}174 + 6118 * T_{\min} - 173 * T_{\min}{}^{2} - 651 * T_{\max} - 1.89 * P - 125 * \text{DRY}; R^{2} = 68\% \tag{5.8}$$

$T_{\min}$ and $T_{\max}$ are the minimum and maximum temperatures (°C), P is the annual rainfall (mm) and DRY is the length of dry months (month). Yield is projected to

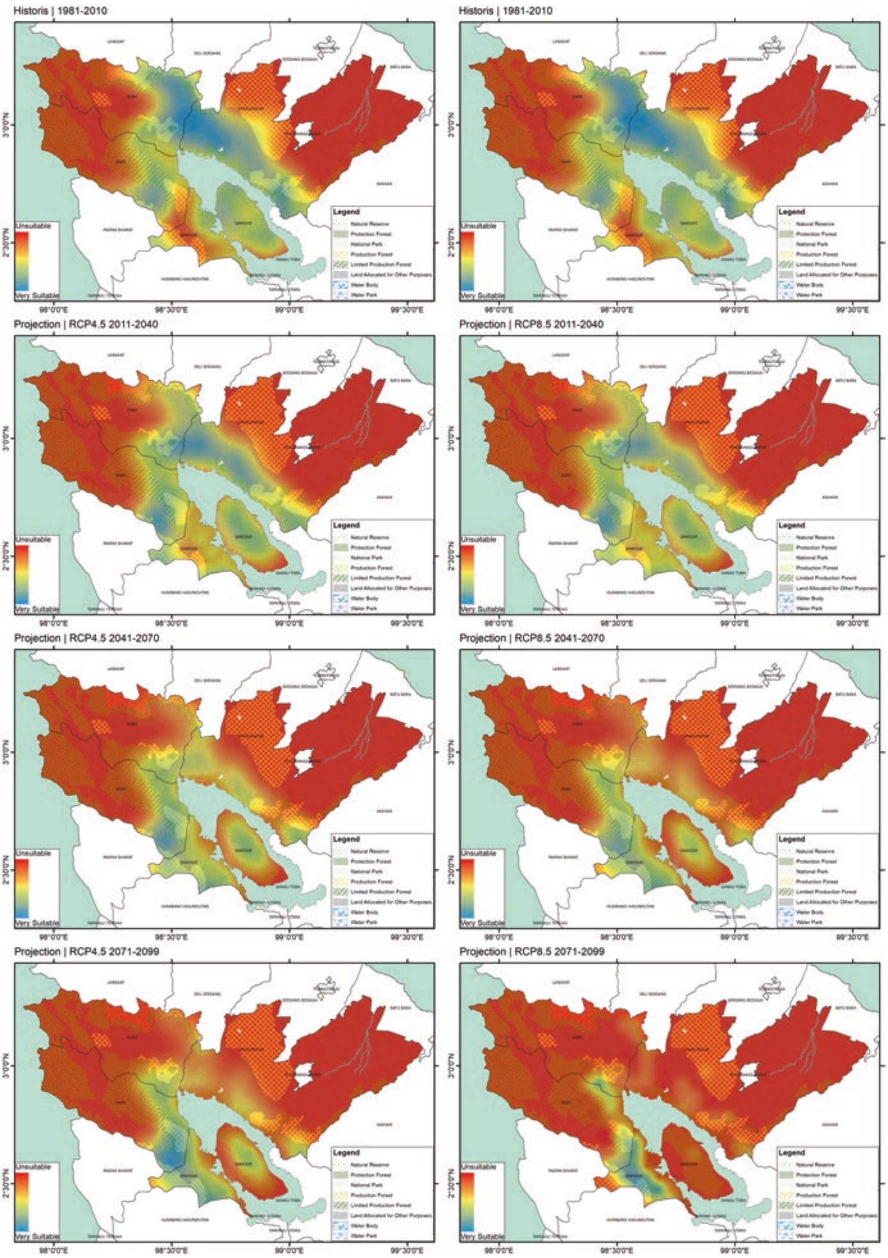


Fig. 5.35 Climate suitability index for coffee plantations in Toba area

decline with the increase of temperature and rainfall in the future. In general, yield is projected to decrease to about 25–75% in the future.

On the contrary, coffee planted on areas 1500 m MSL currently classified as not very suitable is projected to yield 1.5 to 2.0 times higher than the current yield or even twice in some areas (Fig. 5.36). This indicates a potential shift of suitable coffee production areas to higher areas currently considered not suitable.

5.5.2.3 Level of Coffee Berry Borer Attack

In addition to direct impacts on phenological development and yield of Arabica coffee, climate change is also projected to exacerbate the outbreaks of certain pests and diseases (Table 5.10). In general, future climate change is projected to increase the level of attack and modify the attack to higher altitude plantations. Pollination agents are also estimated to decline under the changing climate, hence flowering will eventually decline too.

The analysis identified that the impact of climate change on pest attack is mostly related to the doubling time (DT). Under the changing climate, DT is estimated to range around 5–14 days (Fig. 5.37). The lower PDI values indicated that the growth rate of coffee berry borer increases, increasing the potential risk of yield loss. PDI is projected to decrease or coffee berry borer population will double in a shorter period. Figure 5.37 depicted PDI projection values from 2071 to 2099 under the RCP4.5 and RCP8.5 scenarios. If RCP8.5 occurs, then the PDI values are approaching 1 in most areas. Research in South America and Africa reported that the population of coffee berry borer is increasing from 2 generations per year in the 1970s to 3.5 generations per year lately. This implies that risks of coffee berry borer attack have continuously elevated from time to time and without immediate actions, these would threaten coffee production.

The increased population of the coffee berry borer in some of the Toba areas are threatening the coffee productions, both in quantity and quality. The larger the damages caused by pests, the higher the loss of production experienced by farmers. The direct and indirect impacts of pest attacks were devastating. Based on the survey interviews, it was found that yield losses due to coffee berry borer attacks in Dairi and Simalungun districts totalled to 40%, and in Karo district about 30–40%, while the most significant loss was observed in Samosir District (50%). The declining coffee production, which currently ranged from 30% to 50%, is projected to increase in the next few decades, if necessary measures are not undertaken.

5.6 Adaptation of Coffee Plantation to Climate Change

A whole body of literature have suggested that global climate change has significant impacts on the growth and yield of coffee. As discussed in the earlier sections of this chapter, the observed changing climates occurring in Toba area (Samosir, Simalungun, Karo and Dairi) were mainly related to the decreasing intensity of rainfall and increasing temperature which were projected to have negative impacts on the growth and production of coffee. The impacts will be exacerbated in the

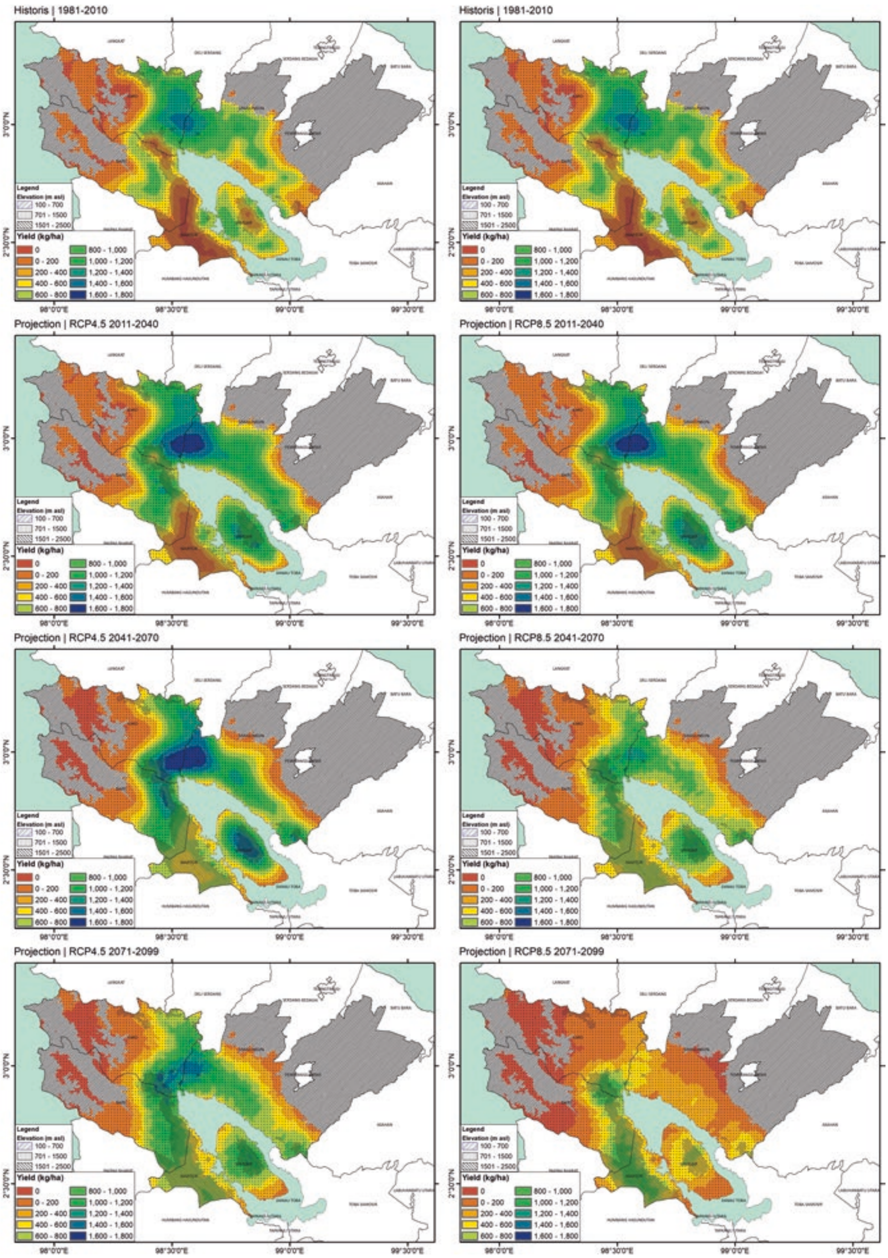


Fig. 5.36 Average yield decreases relative to current yields in Toba area

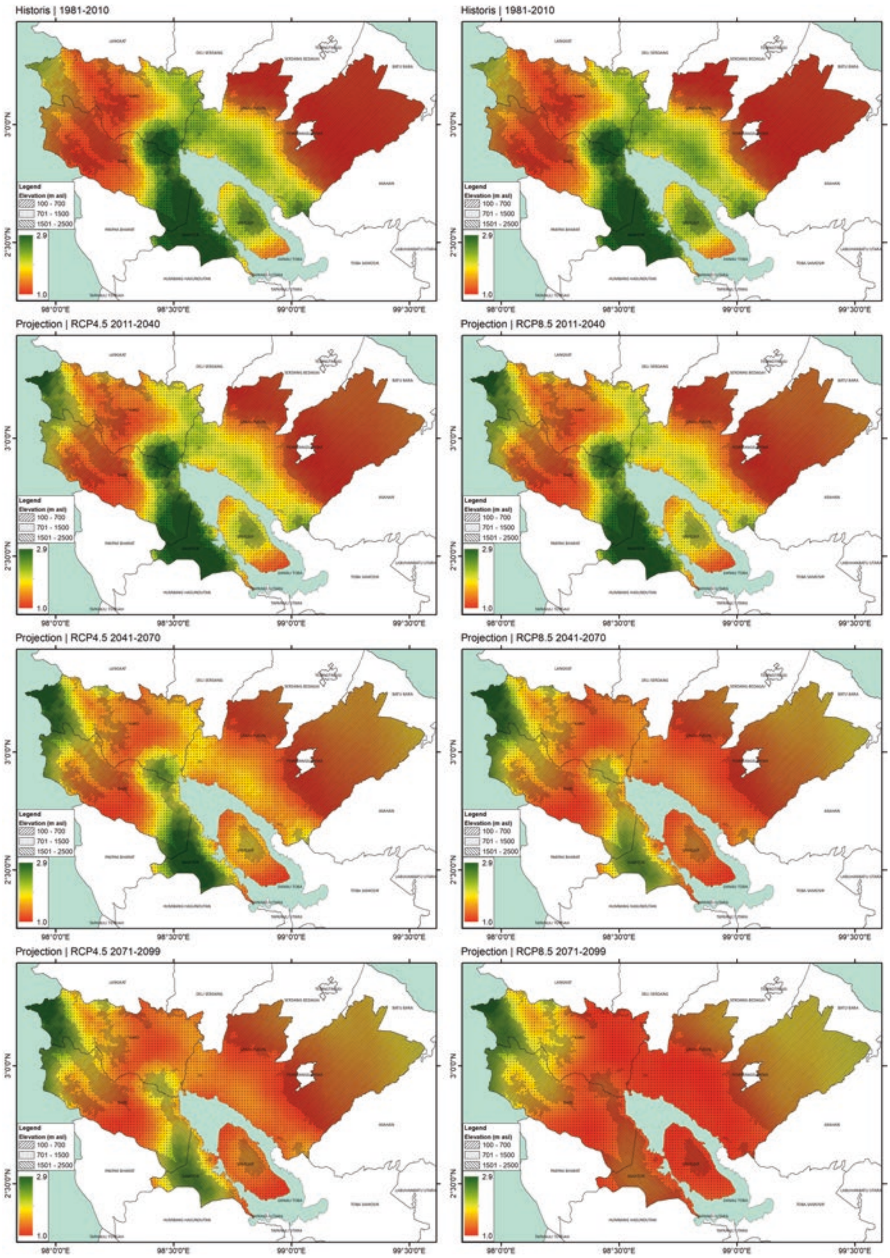


Fig. 5.37 Population doubling index (PDI) of coffee stem borer (coffee berry borer) in Toba (2011–2040; 2041–2070; and 2071–2099) under two projection scenarios ($DT(t_0)$ = 4.94 days)

absence of optimum cultivation techniques. Adaptation measures should therefore focus on improving the cultivation techniques and the technology to cope with drought and warmer temperature in coffee production centres, for example, through shade control, addition and management of organic matter, balanced fertiliser application, regular pruning, harvest and post-harvest management and improvement of pest/disease control – especially on coffee berry borer.

5.6.1 Planting and Management of Shade Trees

Pujiyanto (2016) states that the micro-climatic condition of coffee plantation is not possible to be altered by cultivation techniques. Yet, shade trees are beneficial to adjust the climatic condition to a certain level. Umbrella-shaped canopies help to mitigate against excessive light, heat and humidity. Located on the equator line, Indonesia has two distinct dry and rainy seasons. During the dry season, the shade will reduce direct soil and plant exposure to sunlight, retain soil moisture and may also reduce evaporation rate. Moreover, shade trees also protect the coffee plants from the risks of strong winds and frost on higher altitude (>1500 m MSL), prevent soil erosion and loss of organic matter and suppress weeds. During the rainy season, shade trees can protect the flowers and berries from falling due to heavy rains.

In particular, shade trees are urgently needed in Samosir area as it is projected that there would be prolonged dry season in the area. Without shade trees, the soil water level will be lower, harming the rooting system and microorganisms in the soil. If the drought remains persistent, the productive age of the plantation may be shorter. As an example, some coffee plantations in Sidikalang, North Sumatra, are unexpectedly experiencing loss of production after reaching the age of 10 years although the average productive period is 25 years.

In response to the changing climate, improved cultivation techniques are urgently required, such as the addition of shade or protective plants to adjust the exposure of coffee plantation to sunlight. Nevertheless, as a consequence, farmers need to schedule extra maintenance to prune the protective plants. Pruning of protective plants is conducted based on the extra treatment required by the coffee plantation. Throughout dry season with higher intensity of sunlight, protective plants canopies are ideally thicker. In contrast, more open space or less thick canopies are useful to maintain the exposures to sunlight and humidity. Shade plants often comprised of legume family that has been acknowledged as fast-growing, wind resistant, robust and require easy maintenance and able to produce high organic matter.

There are two types of shade plants, the temporary and the permanent shades. Temporary shades are vital during the preparation of permanent shade and before the productive phase of coffee plants. Most common temporary shade plants are *Moghania macrophylla*, followed by *Crotalaria usaramoensis, C. juncea* and *C. anagyroides*. Temporary shade plants should be trimmed, reduced or even pulled

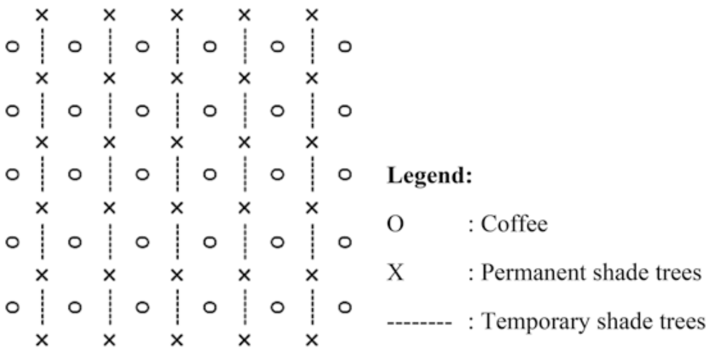


Fig. 5.38 The arrangement of temporary and permanent shades on a young coffee plantation

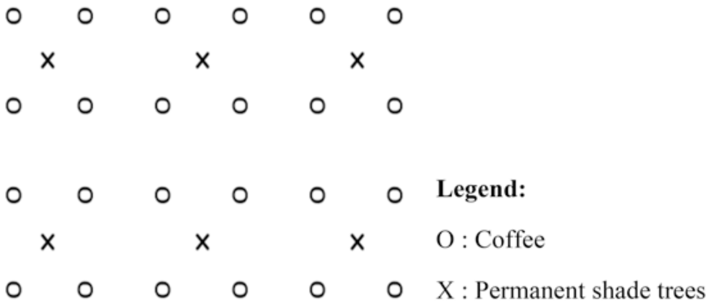


Fig. 5.39 The arrangement of permanent shade trees and coffee (has been 3 years in the productive phase)

completely once the permanent shade is ready and coffee plants come to the production phase. Litters from the temporary shade plants are often applied to the soil to add organic matters. Recently, it is suggested to plant eggplant, corn or beans as temporary shade plants so that farmers can benefit from harvesting the yield before getting benefit from the coffee plantation.

Best permanent shade plant is *Leucaena glauca* klon L2, or other common shade plants including *Gliricidia sepium, G. maculata*. In agroforestry, stands of forest trees such as *Durio zibethinus, Altingia excelsa* Noronha, *Swietenia mahagoni, Shorea* sp. *and Agathis dammara* can serve as permanent shade plants for coffee plantation. Else, productive fruit plants can also be favourable as shade trees such as *Parkia speciosa*, durian, avocado or orange.

Figure 5.38 gives an illustration of coffee and shade trees arrangement plots, both temporary and permanent shades. Moreover, Fig. 5.39 depicts permanent shade trees with coffee at the age of 6 years (has been in productive phase for 3 years). An example of a coffee plantation with *Leucaena leucocephala* is shown in Fig. 5.40.

Fig. 5.40 Example of a coffee plantation with *Leucaena leucocephala* (*lamtoro*) as shade trees

The ratio of shade trees to coffee is 1:1 for a young coffee plantation, while the ratio is 1:4 for permanent shade tree and coffee on the production phase. Once the coffee plants come into the production phase, temporary shade trees will be pulled out and applied as extra organic matter to the soil. Maintenance of shade trees include regular trimming of the branches to keep the height below 3 m and cutting small shoots that appear more frequently during the rainy season.

Most coffee plantations in Toba are monoculture, only small area practices polyculture. In general, monoculture coffee does not use shade tree to control exposure to sunlight. Extreme sunlight exposure has detained the plants to have optimum growth, yellow leaves, thicker, less chlorophyll and biennial bearing of production by year. Addition of shade trees as in Fig. 5.40 is thus relevant in this context.

Polyculture coffee plantation also often combined fruits with forest stands. Unlike monoculture, polyculture coffee shows healthier growth with green and thin leaves and fruitful vegetative phase although the production might be lower during the rainy season. The extra coverage from shade trees reduced the penetration of sunlight causing the coffee plants to receive lower amount of sunlight important for initiating flower. Regular pruning of shade trees may adjust the level of sunlight intake to 70–80%. Another option would be to trim the water shoots 1–2 times a month.

5.6.2 Addition of Organic Matter

Organic matter is a fraction of living organism, both plant and animal. Organic matter is a good source of minerals for plants once they are decomposed by bacteria,

Table 5.16 Suggested type and dosage of fertiliser for coffee plantation

Plants age (year)	Dose (g/plant/year)				
	Urea	SP36	KCl	Kieserit	Dolomite
1	40	50	30	15	30
2	100	80	80	40	50
3	150	100	100	60	80
4	200	100	140	75	110
5–10	300	160	200	100	150
>10	400	200	250	140	200

Source: Puslitkoka (2013) and PT Perkebunan Nusantara XII (Persero) (2013)

fungus or other organisms into CO_2, H_2O and mineral. Organic matter increases the ability of soil to retain water, increase cation exchange capacity (CEC), microorganism activities, retain minerals, improve soil structure and aeration. The main soil types found within the study area were entisol, inceptisol and ultisol with coarse, slightly coarse and mild textures, which are relatively low in organic matter, N and other nutrients. Such soil conditions commonly occurred in soils with high acidity (low pH). Extra applications of organic matter, compost and fertilisers are necessary to improve the soil nitrogen availability, soil quality and soil physical, chemical and biological characteristics.

Under changing climate that mainly affected by changes in rainfall pattern and temperature, an extra application of organic matter can minimise the impacts of climate change such as water and heat stresses. Both small and large coffee plantations have considerable sources of organic matters. The organic matters may originate from shade trees' pruning wastes, coffee pruning wastes, weeding wastes and coffee processing wastes (berries skin). The potential range of organic matters from these activities is about 15–20 t/ha annually. In principle, organic matters from coffee plantations should be kept and returned to the soil in the plantation.

Organic matter is applied to young and mature plants by spreading them over the surface as mulch 10–20 per kg per plant per year. Application of organic matter also helps the plants to maintain optimal humidity throughout the dry season. Another option of application during the rainy season would be to make holes or create a channel for spreading the organic matter. Burying the organic matters in holes or channel will avoid rotten shoot.

5.6.3 Fertiliser Application

Fertiliser is extra nutrients added to the soil or plants to improve the plants' nutrient level. Fertiliser application should follow six correct steps in terms of type, dosage, time, way, placement and supervision. Type and dosage of fertiliser are based on the analysis of the soil and leaves. In the case that an analysis cannot be conducted, the farmers should refer to the Guidelines from the Indonesian Coffee and Cocoa Research Center (Table 5.16).

The minimum number of fertiliser's application is twice a year – the first application should be made by the onset of the rainy season (Oct/Nov) and the second application by the end of rainy season (Mar/Apr). Urea, SP36 and KCl are mixable as long as they are applied within a short period after the mix. Kieserite (magnesium sulphate mineral) and Dolomite can be used as substitution for each other. Application of Kieserite or Dolomite is in sequence with Urea/SP36/KCl. Fertiliser channel in between coffee plants is ideally 20 cm wide and 10 cm depth. The fertiliser is spread on to the channel and covered with soil on top (buried). Fertiliser application needs serious supervision, especially on dosage, application and selection of the location to be applied.

Farmers in the study areas rarely applied extra fertiliser for their plants; few sometimes applied fertiliser without appropriate dosage and without considering the needs of their plants. On the other hand, Sigararutang which is the common cultivar in the area needs a higher amount of nutrients to produce an optimum growth. The cultivar needs at least 0.5 kg of inorganic and 10 kg of organic fertiliser. This is reasonable since the coffee plants in the area showed some unhealthy symptoms like yellowish leaves, dried branches, easily infected by diseases and less producing berries.

Farmers did not regularly apply fertiliser due to limitations in financial capital, knowledge of plant growth or human resources working on the plantation. One of the common socio-economic problems observed in the study areas was the age of farmers. Older generation were seen working as farmers, while most of the young generation prefer to work in big cities.

5.6.4 Pruning

Pruning or trimming of coffee plants are alternatives to manage the stability of production and to avoid biennial-bearing due to absorption of extreme sunlight and temperature. Biennial-bearing occurred when coffee plants are overexposed to the sun in one season, causing a high number of flowering and berry production, but followed by rapidly declining yields in the next season. Coffee grows productive branches during vegetative phase followed by berry branches. A higher number of productive branches assured higher yields and vice versa (Yuliasmara et al. 2016).

Pruning is necessary for both immature and productive plants. For immature plants, pruning aims to shape while for productive plants, pruning aims to maintain production. Shaping the immature plants would ensure the plants to grow strong, balanced and produce well. The plants are maintained to a certain height to simplify the harvesting process, branches are sturdy and well balanced, and there is good air circulation. Pruning can be conducted in two steps. The first step is toping, to adjust to the desired height, and then followed with pruning unwanted branches. On flowering and robust plants, direct cut at the height of 1.8 m is possible. Weaker plants are first cut at the height of 1.2 m and then re-cut at 1.8 m in the next year. In general, 1.8 m is ideal to allow harvesting to go smoothly without damaging the branches. The second step of pruning is to clear unwanted branches, for each 60 cm zone, to stimulate new and healthier branches growth.

Pruning of productive plants aims to maintain the height of plants at 1.7–1.8 m, to stimulate new and healthier branches that would lead to higher production, to optimise sunlight penetration and air circulation, to support primordial development and flowering, to remove unwanted branches, to control pest and disease and to obtain ideal shape.

Production/maintenance pruning consists of post-harvest pruning and removal of water shoots. Post-harvest pruning is conducted directly after the harvest, involving cutting unproductive branches (branches B3, branches that have been producing berries three times; adventive branches, wormed, turned, fan-shaped; infected branches; dried and damaged branches). Pruned plants should have a balanced proportion of strong branches of category B0 (not producing yet), B1 (producing once) and B2 (producing twice) each having equal composition of 33%. Some farmers maintain the branches to produce up to three times. In such case, the composition of B0:B1:B2:B3 would be 30%:30%:30%:10% to support sustainable production. The water shoots are removed 3 months after post-harvest pruning. Pruning is a skill-intensive operation and it is essential for the growth of coffee plants and coffee production.

Farmers in the study area did not prune their plants, few occasionally pruned parts of the plants randomly. Irregular pruning does not help plants to grow better, in fact, the height remains unfavourable for harvesting (Fig. 5.41a), drying branches, imbalance composition of B0, B1, B2 and B3. Unpruned coffee plants in the study areas showed the symptoms of having scattered new branches on top, but no new branches grown in the lower parts of the plant. Further, unpruned coffee tends to have a shorter economic period, their ability to produce berries is rapidly decreasing with time (Fig. 5.41b). In contrast, pruned plants' ability to produce berries is increasing with time (Fig. 5.41c).

5.6.5 Harvest

Harvest is the final process in crop production before the product entered post-production process. Harvesting determines the quality and quantity of the product. Therefore harvesting needs to follow specific procedures, such as selective picking (only pick red and ripe berries), ensuring no damage on stems and no falling berries around the plants. As a consequence of selective harvest, there is a picking rotation about 7–15 days continuously which requires human resources accordingly. Even with selective picking, we cannot avoid yellow or green berries picked at maximum tolerance of 10%. Blackened and dried berries should also be picked to avoid infection of pest or diseases into the plants – especially coffee berry borer.

Farmers in the study area usually performed semi-selective harvest (Fig. 5.42). Yellow and green berries were also picked, although it might lower the quality of the coffee. Harvesting system will influence further processing. Selective harvest (only red berries) will be followed by wet processing to produce high-quality green beans.

Fig. 5.41 Condition of plants with and without pruning in Samosir District (**a**) and Karo District (**b** and **c**)

Semi-selective harvest should be followed by a sorting process to separate red berries from green and yellow berries, red berries will be processed wet while others will be dry-processed. The dry process often results in lower quality beans.

5.6.6 Pest Management

Pest control in Toba is not merely about technology or technique but also socio-economic challenge related to the awareness of the farmers to remove infected plants because even damaged/low-quality berries are still saleable. Farmers are not aware of the symptoms, i.e. unhealthy plants; thus they were resistant to adopt pest control technologies.

However, reduction of risk to coffee berry borer in the future should be listed as a priority and supported by field school on integrated pest management (FSIPM). Farmers could learn pest management control from FSIPM that would allow them to have better skills to handle infected plants in the future (Table 5.17). Currently,

Fig. 5.42 Harvested berries from one of the coffee plantations in Samosir

the conventional techniques to deal with coffee berry borer are by introducing its biological control agent *B. bassiana,* use of a trap and population monitoring, but they have been limited to a single measure. Thus, an integrated coffee berry borer control is necessary.

Another option for adaptation is to plant varieties that are more resilient to climate stress. Technical control such as shade management and pruning should be conducted interactively. As indicated in earlier sections, pruning is aimed to maintain sun radiation, humidity and temperature at optimum level for coffee production. In addition, sanitation, weed control and balanced fertiliser application are also necessary. Fallen berries post-harvesting should be cleared to cut the life cycle of the coffee berry borer. Use of *B. bassiana* as a biological agent to control coffee berry borer is also beneficial.

Controlling the coffee berry borer needs a holistic and integrative approach, because there is no single solution to annihilate the pest. For the coffee berry borer control technology to be effective in removing the pest completely, it must be accompanied with regular maintenance of the plantation. Other supporting factors include farmers' commitments and knowledge to conduct integrative intervention, as well as the availability of institutional support, guidance and support from the government in FSIPM.

Some farmers relied heavily on insecticides and traps to control pests or diseases. However, the results were varied and unpredictable. Despite the increasing number of research, pest and disease remain persistent in coffee plantation across the country. Integrated Pest Management (IPM) is the major procedure to abolish coffee berry borer using an ecological approach. IPM strategies involved regular monitoring to evaluate the economical and environmental impacts from pest control. This suggests that farmers should master the basic knowledge and techniques in pest

Table 5.17 Summary of pest and disease management control in coffee production

OPT	Control
Coffee berry borer (*Hypothenemus hampei*)	Cut the life cycle
	Introduction of biological control agents such as *Beauveria bassiana* or parasitoid *Cephalonomia stephanoderis*
	Trap
Twig borer (*Xylosandrus morigerus* and *Xylosandrus compactus*)	Technical intervention: improve sanitation, cutting or burning infected stem
	Balanced fertiliser and maintenance
	Introduction of biological control agents such as parasitoid *Tetrastichus xylebororum*
Striped mealybug (*Ferrisia virgate*) harms the stem and leaves	Technical intervention, biological and chemical control
	Introduction of biological control agents such as *Nephus roepkei, Scymus apicivlavus, Cryptolaemus montrouzieri, Brumus suturalis*
	Technical culture w/ addition of shade to maintain humidity
	Chemical: application of insecticide
Coffee leaf rust (*Hemileia vastatrix*)	Technical intervention: reduce humidity (by pruning shade trees and unproductive branches of coffee plants)
	Introduction of biological control agents such as *Verticillium lecanii* or *Trichoderma* spp.
	Balance of fertiliser application to improve plants immunity to pest and disease
Brown eye spot (*Mycosphaerella coffeicola* or fungi *Cercospora coffeicola*)	Technical intervention: reduce humidity (by pruning shade trees and unproductive branches of coffee plants), improve drainage
Pink diseases (*Corticium salmonicolor*) harm the stem, branches, and berries	Technical culture: reduce humidity (by pruning shade trees and unproductive branches of coffee plants)
	Shade trees management
Root disease (*Phellinus noxius*, *Rosellinia bunodes*, and *Rigidoporus microporus*)	Pull out infected plants and its roots

control and also be able to estimate infestation. General information is available in plantation pest control guidebook published by the Directorate General of Plantation, Ministry of Agriculture, on “Technical Guidebook on Crop Pest Organism of Coffee” (Harni et al. 2015).

5.7 Conclusion

Climate change would have significant impacts on the growth and development of coffee plantations in the Toba Region. Following changes in rainfall, the coffee phenology, flowering season and peak of harvesting would experience some shifts.

Similarly, crop yields would also decline due to the changes in rainfall patterns and rising temperatures, which would ultimately increase the number of pest and disease attacks, especially of the coffee berry borer. The current technology adoption by the farmers is still inadequate. Without serious and integrated efforts to improve cultivation technology, impacts of climate change would be exacerbated.

Beyond reducing yields and amplifying pest and disease attacks, climate change has the potential to shift upwards the suitable climate area for coffee production to higher elevation and threaten the existence of protection forests. Current lands under the suitability classifications of "very suitable" and "suitable" are facing some alteration to become "less suitable" and "unsuitable" areas in the future.

5.8 Recommendation

In addition to cultivation techniques, there are some specific measures to overcome and reduce the impacts of climate change on coffee productions:

- Development of nurseries from selected parent trees. This requires specific assessment with experts and practitioner on the identification of selected parent trees.
- Development of Arabica coffee should focus on increasing yield through intensification, rehabilitation and replantation.
- Necessary steps for intensification include socialisation, maintenance of plants based on technical operational standard (SOP) that highlights weed control, fertiliser application, pruning, shade trees management and pest and disease control.
- Replantation activities must comprise of the following steps: Socialisation programme, preparation of seeds, preparation of protective/shade trees, pulling out old plants, spacing design, planting shade trees, digging planting holes, planting and maintenance.
- Rehabilitation activities must include socialisation programme, preparation of entrees, cutting stems of old plants and maintenance of water shoots which will be connected by grafting.
- Expansion programme involves socialisation, measurement of the area, preparation of seeds, preparation of shade trees, spacing, planting shade trees, digging holes, planting and maintenance.
- In order to improve dry beans quality, it is necessary to have a post-harvesting unit complete with berry skin peeler, drier and sorting machine. Roasting machine is also necessary. Cheap and locally available energy sources should be used as fuels. It is also necessary to develop coffee processing SOP to sell high-quality Arabica.
- To increase the selling point of Arabica coffee in the market, promotion by local government in collaboration with coffee exporters association (AEKI), *Disperindag* or private (CSR) is essential. This would create strong branding of Toba coffee in both domestic and international markets.

- The coffee trading system needs to be improved to enhance the bargaining position of coffee farmers and provide a fair distribution of benefits among the farmers.
- Skilled and knowledgeable human resources are necessary for coffee-growing activities. Both formal and informal educations such as training, counselling, workshops and field schools should be set as capacity building for farmers in the area. In parallel, it is necessary to initiate a pilot project that entirely adopts guidebooks on coffee cultivation as a real laboratory for farmers to learn.
- Infrastructural improvement in transportation is also necessary to support post-harvest processing.

Continuous and integrated control of coffee berry borer should at least consider the following:

- *Use of resistant varieties*: Resilience to coffee berry borer varied among some of the coffee varieties planted in Toba region. This would require research to identify resistant varieties that could provide the highest yield.
- *Pruning and clearing up of falling berries*: Pruning will ensure coffee plants are exposed to an optimum level of sunlight, humidity and temperature. Maintaining a micro-climatic condition can also keep away pest and disease. *Rampesan* or clearing falling berries aim to cut food supply for Coffee berry borer and eventually cut its life cycle. This would be useful only if all of the coffee farmers in the area practising the same strategy, otherwise, Coffee berry borer would move from one plantation to another within the neighbourhood.
- *Use of biological control agents* can naturally reduce the population of pests. Examples of biological agents are *Cephalonomia stephanoderis* (Hymenoptera: Bethylidae) or *Beauveria basiana* that are known as parasites to coffee berry borer and has been proven to be successful to minimise the population of coffee berry borer. This parasite should be introduced in the early planting years while the pest population is still low. Furthermore, training on parasitoid breeding for farmers is required to allow them to be able to breed their variety, thus do not rely upon other sources.
- *Pheromones/attractant trap*: Coffee berry borer traps have been common in the market. Use of traps is often suggested before or during harvest as the Coffee berry borer starts to find new food sources during this period. On an average, a farmer needs 18 traps/ha, set with a spacing of 24 m and a height of 1.2 m. Nevertheless, using traps is very costly and less effective, if only used by few farmers. For more effective control, all farmers in the area should set the trap at the same time and regularly reapply in combination with other pest control methods.
- *Insecticide*: In the context of outbreaks, the use of insecticide is possible, but with a rigorous procedure in a way that does not harm the surrounding environment. Field School for Integrated Pest Management (FSIPM) is an ideal programme to introduce the basic concept of integrated pest control. Knowledgeable farmers are more sustainable in maintaining their plantations in the correct way, as they are entirely aware of the consequences.

- *Support from the government*: Implementation of programmes in Indonesia is currently relying on government supports for technicalities and financial and comprehensive guidance. However, the existence of institutions for integrated pest management guidance might reduce this dependency in the near future.

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