Research Article

Effect of Agroforestry and Natural Forest on Air Surface Temperature in Eastern Phi Pan Nam Mountain Range Area, Thailand

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ABSTRACT

In this study, the air surface temperature variation in the agroforestry and natural forest areas in Eastern Phi Pan Nam mountain range, Uttaradit Province was studied by selecting the plant communities in a traditional agroforestry in Mae Phun Subdistrict, Laplae District (LP-AF), an applied agroforestry in Ban Dan Na Kham Subdistrict, Mueang Uttaradit District (DK-AF), and a developed agroforestry in Nang Phaya Subdistrict, Tha Pla District, Uttaradit Province (NP-AF), as well as two natural forest areas in Eastern Phi Pan Nam mountain range, Uttaradit Province which were a mixed deciduous forest (LN-NF) and a hill evergreen forest (PP-NF) in Lamnam Nan National Park, Uttaradit Province in order to establish the sample plots and install the automatic weather stations for recording the average daily temperature over a period of 9 months. According to the results, the lowest average temperature of 37.32°C was observed in the traditional agroforestry in Mae Phun Subdistrict, Laplae District (LP-AF) and the average air surface temperature of the applied agroforestry in Ban Dan Na Kham Subdistrict,

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Mueang Uttaradit District (DK-AF) was 28.30°C which was 0.98°C higher than that of the agroforestry in Mae Phun Subdistrict, Laplae District (LP-AF). In addition, it was found that the average air surface temperature of the agroforestry in Nang Phaya Subdistrict, Tha Pla District, Uttaradit Province (NP-AF) was 28.07°C which was 0.75°C higher than that of the agroforestry in Mae Phun Subdistrict, Laplae District (LP-AF). All these 3 agroforestry systems showed no difference in the average air surface temperature compared to the mixed deciduous forest. However, significant difference was observed when all these 3 agroforestry systems were compared to the hill evergreen forest at a confidence level of 95%.

Keywords: Air surface temperature, Agroforestry, Natural forest, Uttaradit province

Introduction

The steady increase in the population of the developing countries inevitably increases deforestation, which has had a detrimental effect on the livelihoods of humans, plants and animals. The rapid forest decline in Northern Thailand, especially Nan Province, has been caused by logging and forest clearing for intensive agriculture. The forests have been destroyed continuously over a long period of time, resulting in ineffective and unprofitable use of forest resources and land. This has led to a steady decline in forest area, with both economic, social and environmental impacts, causing conflicts in resource utilization. Therefore, the use of agroforestry for the production of agricultural products is an important approach to establish the balanced agricultural development mechanisms with ecological preservation [1]

Uttaradit Province is an important cultivation area for durian, langsat and Southern langsat in Northern Thailand, which have been cultivated in 3 districts: Mueang District, Laplae District and Tha Pla District. Cultivation of the fruit trees in these areas has been performed in form of agroforestry since the ancestor of the Uttaradit people. The influencing factors due to population increase are the transformation of agriculture system from traditional agriculture for living to commercial agriculture, more cultivation of economic crops for example transformation of original forests for cultivating the fruit trees such as durian and Southern langsat in the mountains which has led to a rapid decline of forest area. In addition, the ecological change from the original natural ecosystem to the agroecosystem has caused land degradation. For example, prolonged monoculture of field crops and horticultural crops have resulted in lower crop yields but higher production costs and significant land degradation. Agroforestry is a land use method where woody perennials (trees, shrubs, palms, bamboos, etc.) are cultivated in the same land-government unit with crops and/or animals, in various type of a spatial agreement or a temporal sequence [2]. Agroforestry is carried out in the temperate, sub-tropical and tropical zones, and it includes a extended range of land uses and systems [3-4]. Agroforestry attributes to link edition and excuse strategies. It provides diverse ways to securing food security for poor farmers in developing countries in particular, while mitigating climate change [5]. Agroforestry often involves the activities that include a combination of long-lived perennials, economic crops, and may also have livestock and fish production. Therefore, in principle, the activities in the system must be harmonized. Each activity should complement each other in order to maximize the benefits of the system, which may be measured by income, food or energy, with minimal impact on the environment. The basic concept of the system is the purposefulness of resources. For example, parts of the plants can be used as food, fuel, wood, or medicine. The canopy is also windproof, and the root systems help prevent soil erosion and increase soil fertility. Agroforestry methods are more complex than monoculture situations. They include of yearly and perennial plants, which are often integrated with livestock [6]. Temperature, humidity and ambient CO2 concentration affect all organisms included in an agroforestry system, potentially in very varied ways, and climate change is projected to alter all of these factors. In light of the high potential of agroforestry for food security [7].This system guarantees that the rural area is utilized for cultivation purposes to meet basic agricultural needs or five factors: crops, food, fruits, herbal medicine, and energy. The plants in agroforestry can be used to build houses and this system also contains the perennials of economic value and pets for continuous and sustainable benefits. Agroforestry is a way of life and agricultural production model of the communities. It also maintains a balance, slows down climate change, and contributes to food security. Tree's coverage is one of the most effective means to relieve a high-temperature environment [8-9]. By increasing solar radiation reflectivity and increasing evaporation that absorbs heat and reduces heat transfer, the temperature can be decreased by up to 0.8-8.4°C [10-11]. As trees in agroforestry provide a range of ecosystem service (ES) that are not directly related to agroforestry production, they are usually referred as companion trees and increasingly promoted as a "climate-smart" practice [12], improving the resilience of agroforestry production by creating favorable microclimate conditions, as well as improving soil health [13-17]. Trees in agroforestry increase the biodiversity that enhances biological control [18-20]. The role of companion trees in climate change adaptation and mitigation needs to be better documented and compared to monocropping systems [17, 21-24]. Therefore, The objectives to develop agroforestry species recommendations along an altitude and climate gradient, using local tree knowledge on ecosystem service provision, and was conducted for the comparison of the physical factors of agroforestry and natural forest areas in Uttaradit Province in order to achieve a balance between farmers' income and ecological sustainability, using natural forest areas as reference.

Methodology

The variation of average air surface temperature or near-surface air temperature in agroforestry and natural forest areas in Eastern Phi Pan Nam mountain range, Uttaradit Province was studied using the following research methodology.

1. Survey and site selection for establishing the sample plots

Plant community selection was performed in a traditional agroforestry in Mae Phun Subdistrict, Laplae District (LP-AF); an applied agroforestry in Ban Dan Na Kham Subdistrict, Mueang Uttaradit District (DK-AF); and a developed agroforestry in Nang Phaya Subdistrict, Tha Pla District, Uttaradit Province (NP-AF); as well as two natural forest areas in Eastern Phi Pan Nam mountain range, Uttaradit Province which were a mixed deciduous forest (LN-NF) and a hill evergreen forest (PP-NF) in Lamnam Nan National Park, Uttaradit Province in order to establish the sample plots. The study areas are shown in Figure 1 and Table 1.

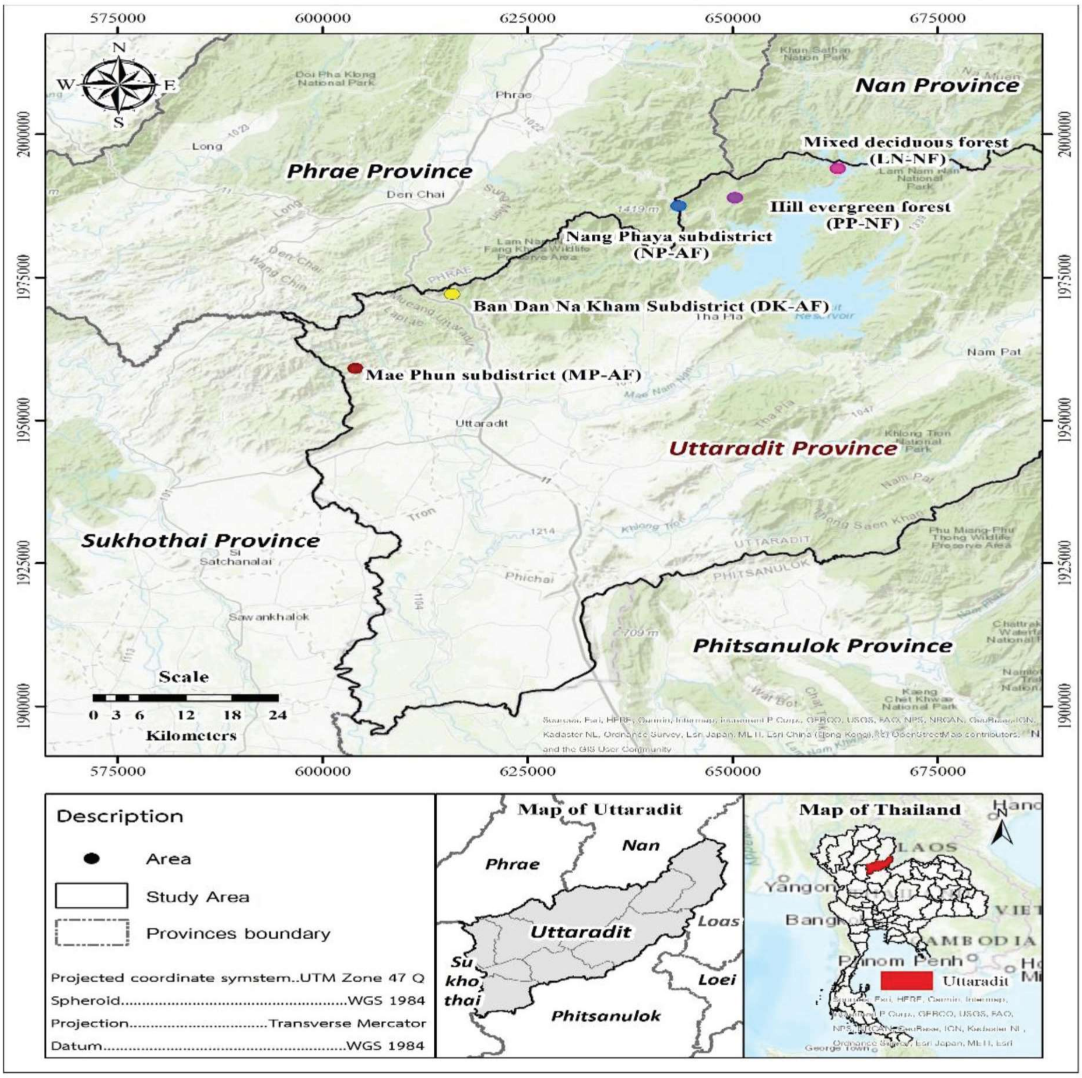

Figure 1 Study areas for determination of air surface temperature variation in various agroforestry and natural forest areas in Eastern Phi Pan Nam mountain range, Uttaradit Province

Table 1 The coordinates of the agroforestry and natural forest areas in Eastern Phi Pan Nam mountain range, Uttaradit Province

Area	Land use	Elevation (m.s.l)	Slope (%)	Vegetation Cover (%)	Geographic coordinates
Nang Phaya Subdistrict (NP-AF)	Agroforestry	864	35	57.5	17° 58′ 16.9″ N 100° 21′ 15.9″ E
Ban Dan Na Kham Subdistrict (DK-AF)	Agroforestry	855	38	66.8	17° 50′ 02.3″ N 100° 05′ 34.6″ E
Mae Phun Subdistrict (MP-AF)	Agroforestry	848	25	65.2	17° 43′ 02.2″ N 99° 58′ 51.9″ E
Mixed deciduous forest (LN-NF)	MDF	838	20	62.6	18° 04′ 01.4″ N 100° 32′ 52.9″ E
Dry evergreen forest (PP-NF)	DEF	862	25	75.3	17° 59′ 01.7″ N 100° 25′ 09.9″ E

The sites for establishing the sample plots were determined by selecting the representative area of each forest community. Each area should have similar physical characteristics of agroforestry and natural forest such as elevation, slope, etc.

2. Establishment of sample plots

Three permanent sample plots (20x50 m^2) per area were established using the belt transect method.

3. Data source air surface temperature

The air surface temperature or near-surface air temperature data was collected over a 9-month period by using automatic meteorological stations for the comparison of air surface temperature of the agroforestry and natural forest areas. Each monitoring point was installed with automatic meteorological stations with pc interface with UV index and lux meter model WH2310 freq 433 MHz with a uniform height of 1.75 m and a sampling frequency of 5 min [25]. To eliminate environmental errors, agroforestry and natural forest monitoring points were set near the center and installed on the trunk of trees of the same or similar variety. Diameter at breast height (DBH), height and canopy, and the monitoring point ensured that the underlying surface was the same or similar. To eliminate instrumental errors, all instruments were placed in the same location for monthly calibration (48 h).

4. Data analysis

The differences between agroforestry and natural forest areas in terms of environmental factors of the microclimate were determined using a t-test, which was determined by using almost version 19 minitab program a statistical software. The relationships between plant community data in each area, the average air surface temperature and the integrity of the agroforestry were analyzed using natural forest areas as reference.

Results and Discussion

The results of the study of the average air surface temperature variation in agroforestry and natural forest areas in Eastern Phi Pan Nam mountain range, Uttaradit Province are as follows:

1. Average air surface temperature

Changes in the average air surface temperature or average near-surface air temperature have an effect on the understory plants or the fruit trees as the understory plants are usually small in size. The air surface temperatures how's the energy balance between soil and air because there is always energy transfer between them. In this study, the average air surface temperatures over a 9-month period in 5 areas: agroforestry systems in Mae Phun Subdistrict, Laplae District; Ban Dan Na Kham Subdistrict, Mueang Uttaradit District and Nang Phaya Subdistrict, Tha Pla District, Uttaradit Province; and natural forest areas in Lamnam Nan National Park and Phu Phaya Poh were recorded. According to the results, the agroforestry in Mae Phun Subdistrict, Laplae District showed an average temperature of 27.32°C in the range of 26-28°C; the agroforestry in Dan Na Kham Subdistrict, Mueang Uttaradit District showed an average temperature of 28.30°C in the range of 26-29°C; the agroforestry in Nang Phaya Subdistrict, Tha Pla District showed an average temperature of 28.07°C in the range of 24-31°C; the natural forest in Lamnam Nan National Park showed an average temperature of 28.81°C in the range of 26-31°C and the natural forest in Phu Phaya Poh showed an average temperature of 25.57°C in the range of 23-27°C. The highest average temperature over a 9-month period was observed in Lamnam Nan National Park, followed by the agroforestry in Dan Na Kham Subdistrict, agroforestry in Nang Phaya Subdistrict, agroforestry in Mae Phun Subdistrict and natural forest in Phu Phaya Poh, respectively as shown in Figure 2.

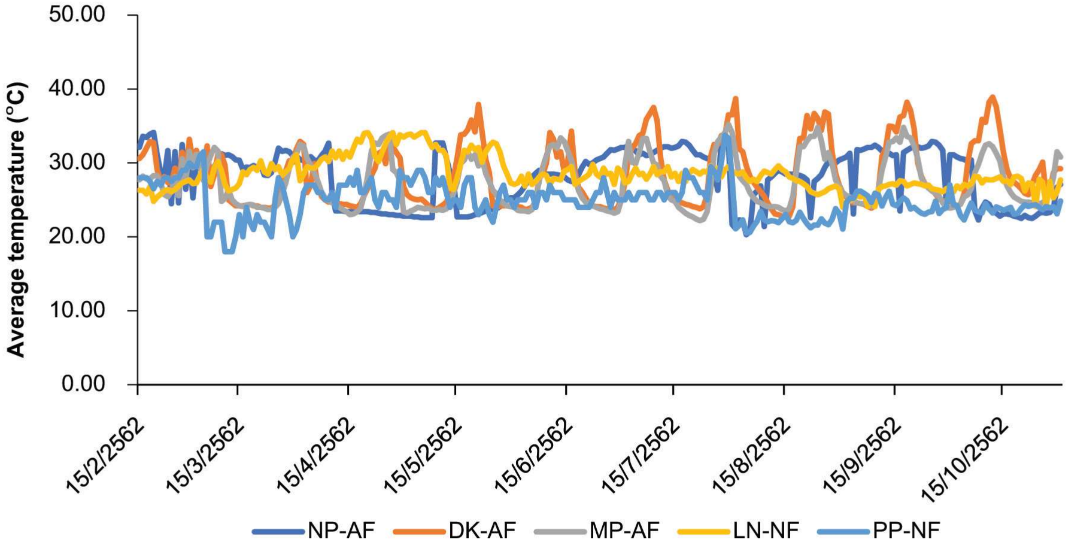

Figure 2 Average air surface temperatures over a period of 9 months in 5 areas

In this study, the average air surface temperatures over a 9-month period in 5 areas: the agroforestry systems in Mae Phun Subdistrict, Laplae District; Ban Dan Na Kham Subdistrict, Mueang Uttaradit District and Nang Phaya Subdistrict, Tha Pla District, Uttaradit Province; and natural forest areas in Lamnam Nan National Park and Phu Phaya Poh were studied. According to the results, the highest average temperature in February was observed in the agroforestry in Nang Phaya Subdistrict, followed by the agroforestry in Ban Dan Na Kham Subdistrict, natural forest in Phu Phaya Poh, agroforestry in Mae Phun Subdistrict and natural forest in Lamnam Nan National Park, respectively. In March, the highest average temperature was observed in the agroforestry in Nang Phaya Subdistrict, followed by Lamnam Nan National Park, agroforestry in Ban Dan Na Kham Subdistrict, agroforestry in Mae Phun Subdistrict and natural forest in Phu Phaya Poh, respectively. The highest average temperature in April was observed in Lamnam Nan National Park, followed by agroforestry in Mae Phun Subdistrict, agroforestry in Ban Dan Na Kham Subdistrict, natural forest in Phu Phaya Poh and agroforestry in Nang Phaya Subdistrict, respectively. In May, the highest average temperature was observed in Lamnam Nan National Park, followed by the agroforestry in Mae Phun Subdistrict, agroforestry in Ban Dan Na Kham Subdistrict, natural forest in Phu Phaya Poh and agroforestry in Nang Phaya Subdistrict, respectively. The highest average temperature in June was observed in Lamnam Nan National Park, followed by the agroforestry in Ban Dan Na Kham Subdistrict, natural forest in Phu Phaya Poh, agroforestry in Mae Phun Subdistrict and agroforestry in Nang Phaya Subdistrict, respectively. In July, the highest average temperature was observed in the agroforestry in Nang Phaya Subdistrict, followed by the agroforestry in Ban Dan Na Kham Subdistrict, Lamnam Nan National Park, agroforestry in Mae Phun Subdistrict and natural forest in Phu Phaya Poh, respectively. The highest average temperature in August was observed in the agroforestry in Nang Phaya Subdistrict, followed by the agroforestry in Ban Dan Na Kham Subdistrict, Lamnam Nan National Park, and agroforestry in Mae Phun Subdistrict and natural forest in Phu Phaya Poh, respectively. In September, the highest average temperature was observed in the agroforestry in Nang Phaya Subdistrict, followed by the agroforestry in Ban Dan Na Kham Subdistrict, agroforestry in Mae Phun Subdistrict, Lamnam Nan National Park and natural forest in Phu Phaya Poh, respectively. In addition, the highest average temperature in October was observed in the agroforestry in Ban Dan Na Kham Subdistrict, followed by Lamnam Nan National Park, agroforestry in Mae Phun Subdistrict, agroforestry in Nang Phaya Subdistrict and natural forest in Phu Phaya Poh, respectively. The results are shown in Figure 3.

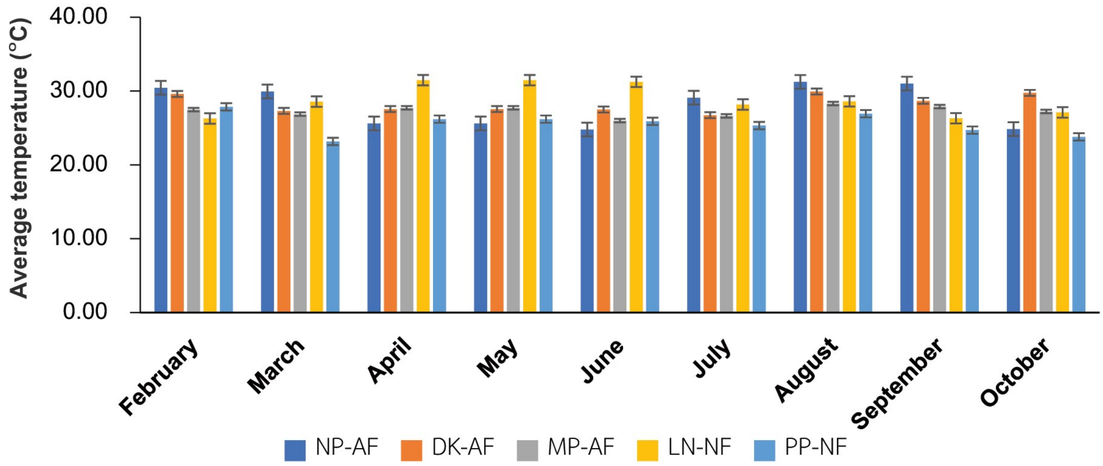

Figure 3 Average air surface temperatures for a period of 9 months in 5 areas by months

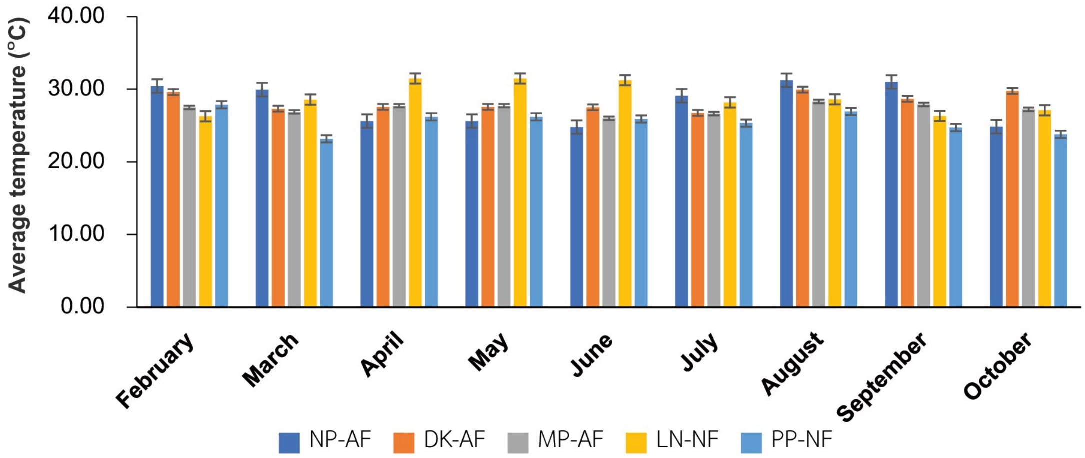

Figure 3 Average air surface temperatures for a period of 9 months in 5 areas by months

1.1 Mae Phun Subdistrict, Laplae District

According to the comparison of average air surface temperatures over a 10-month period of the agroforestry in Mae Phun Subdistrict, Laplae District and 2 natural forest areas which were Lamnam Nan National Park and Phu Phaya Poh, significant difference at a confidence level of 95% was observed between this agroforestry and 2 natural forest areas in 9 months: February, March, April, May, June, July, August, September and October. The average air surface temperature of the agroforestry in Mae Phun Subdistrict, Laplae District showed significant difference compared to that of Phu Phaya Poh, but significant difference was not observed between the agroforestry in Mae Phun Subdistrict and Lamnam Nan National Park at a confidence level of 95% as shown in Figure 4 and Table 2.

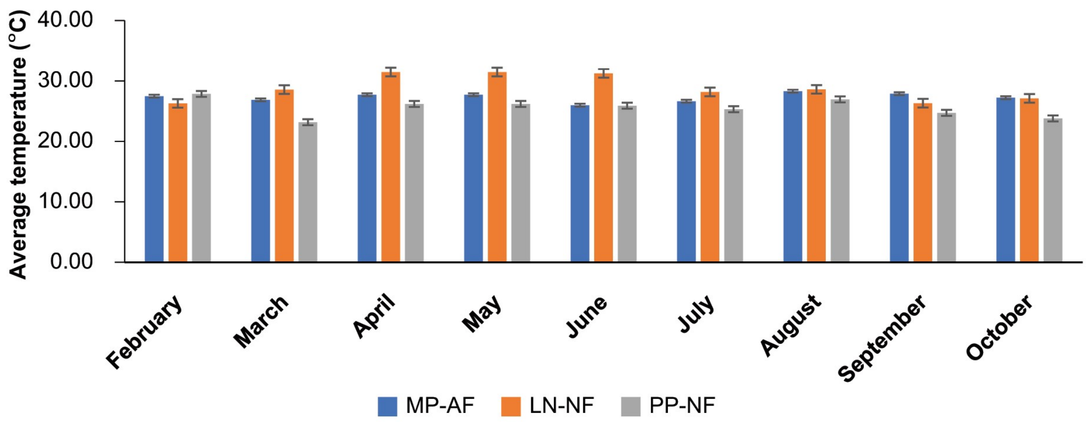

Figure 4 Comparison of the average air surface temperatures for a period of 9 months between agroforestry in Mae Phun Subdistrict and natural forest areas

1.2 Nang Phaya Subdistrict, Tha Pla District

According to the comparison of average air surface temperatures over a 9-month period of the agroforestry in Nang Phaya Subdistrict, Tha Pla District and 2 natural forest areas which were Lamnam Nan National Park and Phu Phaya Poh, significant difference at a confidence level of 95% was observed between this agroforestry and 2 natural forest areas in all 10 months as shown in Figure 5 and Table 3.

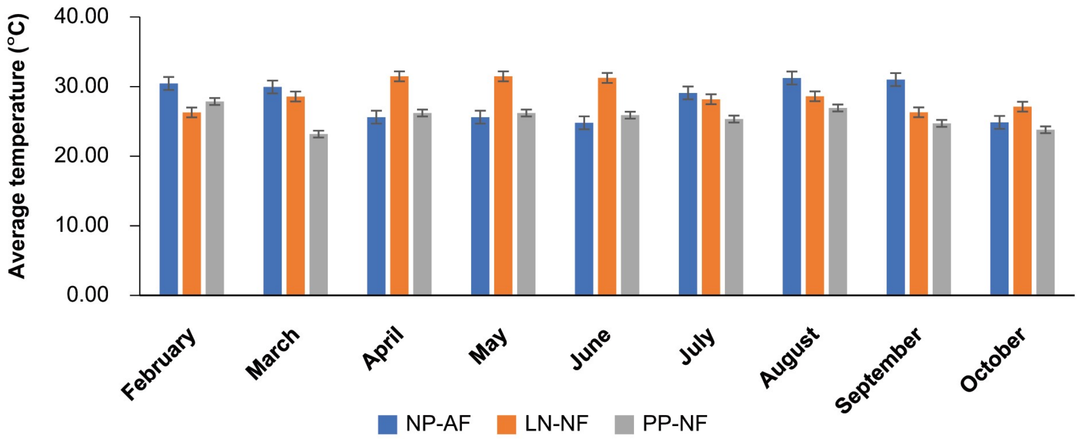

Figure 5 Comparison of the average air surface temperatures for a period of 9 months between the agroforestry in Nang Phaya Subdistrict and natural forest areas

Table 2 Statistical analysis of the average air surface temperatures for a period of 9 months between agroforestry in Mae Phun Subdistrict and natural forest areas

Month	LN-NF	PP-NF
February	Λ **	V **
March	V **	Λ **
April	V **	Λ **
May	V **	Λ **
June	V **	NS
July	V **	Λ **
August	NS	Λ **
September	Λ **	Λ **
October	NS	Λ **

Remark: ** - represents statistical difference t-test between values at a confidence level of 95%; Λ- higher temperature; V lower temperature; and NS - no statistical difference

Table 3 Statistical analysis of the average air surface temperatures for a period of 9 months between the agroforestry in Nang Phaya Subdistrict and natural forest areas

Month	LN-NF	PP-NF
February	Λ**	Λ**
March	Λ**	Λ**
April	V**	V**
May	V**	V**
June	Λ**	Λ**
July	Λ**	Λ**
August	Λ**	Λ**
September	Λ**	Λ**
October	V**	Λ**

Remark: ** - represents statistical difference t-test between values at a confidence level of 95%; Λ- higher temperature; V lower temperature; and NS - no statistical difference

1.3 Ban Dan Na Kham Subdistrict, Mueang Uttaradit District

According to the comparison of average air surface temperatures over a 9-month period of the agroforestry in Ban Dan Na Kham Subdistrict, Mueang Uttaradit District and 2 natural forest areas which were Lamnam Nan National Park and Phu Phaya Poh, significant difference at a confidence level of 95% was observed between this agroforestry and 2 natural forest areas in all 9 months as shown in Figure 6 and Table 4.

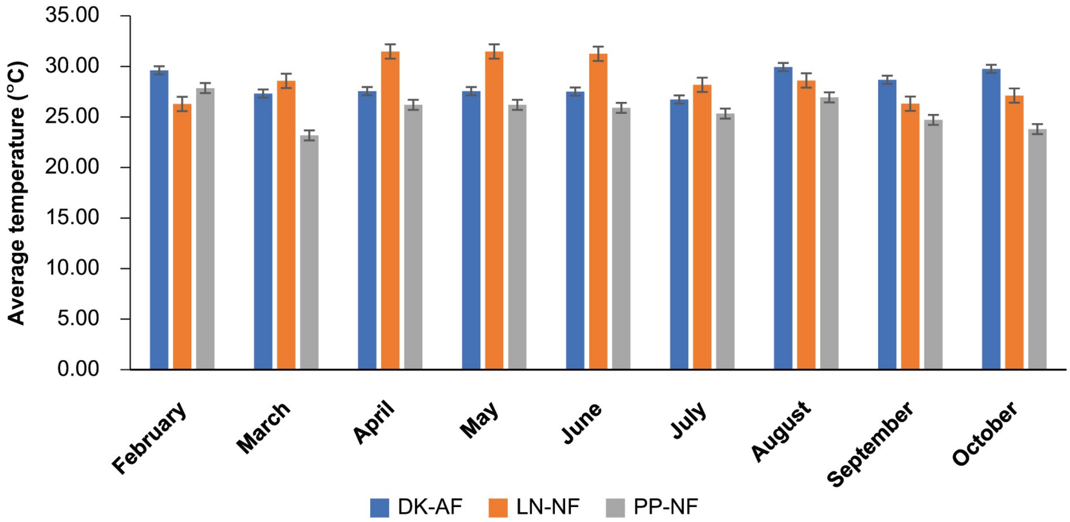

Figure 6 Comparison of the average air surface temperatures over a 9-month period between the agroforestry in Ban Dan Na Kham Subdistrict and natural forest areas

Table 4 Statistical analysis of the average air surface temperatures over a 9-month period between the agroforestry in Ban Dan Na Kham Subdistrict and natural forest areas

Month	LN-NF	PP-NF
February	Λ**	Λ**
March	V**	Λ**
April	V**	Λ**
May	V**	Λ**
June	V**	Λ**
July	V**	Λ**
August	Λ**	Λ**
September	Λ**	Λ**
October	Λ**	Λ**

Remark: ** - represents statistical difference t-test between values at a confidence level of 95%; Λ- higher temperature; V lower temperature; and NS - no statistical difference

2. Relationships between plant community and average air surface temperature

According to the study of relationships between average air surface temperature of various systems and factors, the correlation coefficients of plant density, number of species and number of plants per plot were 0.032, 0.0042 and 0.0185, respectively. No significant difference was observed in the average air surface temperatures between all three agroforestry systems and Lamnam Nan National Park. However, significant difference was observed when all three agroforestry systems were compared to Phu Phaya Poh at a confidence level of 95% as shown in Table 5.

Table 5 Statistical analysis of the monthly average air surface temperatures between the agroforestry and natural forest areas

Area	Temperature range (°C)	Average temperature (°C)	Elevation (m)	Forest type	The difference	
					LN-NF	PP-NF
NP-AF	24-31	28.07	794	MDF	NS	**
DK-AF	26-29	28.30	150	MDF	NS	**
MP-AF	26-28	27.32	440	DEF	NS	**
LN-NF	26-31	28.81	230	DDF		
PP-NF	23-27	25.57	960	HEF		

Remark: ** - represents statistical difference t-test between values at a confidence level of 95%; and NS - no statistical difference

Discussion

In this study the average air surface temperatures over a 9-month period in 5 areas: the agroforestry systems in Mae Phun Subdistrict, Laplae District; Ban Dan Na Kham Subdistrict, Mueang Uttaradit District and Nang Phaya Subdistrict, Tha Pla District, Uttaradit Province; and natural forest areas in Lamnam Nan National Park and Phu Phaya Poh were studied. According to the results, the average air surface temperatures of the agroforestry and natural forest areas ranged between 24-31°C and 23-31°C, respectively. The performance of agroforestry is of great importance and influenced by climate variability and is extremely sensitive to temperature changes [15, 24, 26-27]. The average temperatures in the Arabica coffee agroforestry systems in Uganda range between 18-23°C [17, 27]. According to the results, the lowest average air surface temperature of 27.32°C was observed in the traditional agroforestry in Mae Phun Subdistrict, Laplae District (LP-AF). The average air surface temperature of the applied agroforestry in Ban Dan Na Kham Subdistrict, Mueang Uttaradit District (DK-AF) was 28.30°C which was 0.98°C higher than that of the agroforestry in Mae Phun Subdistrict, Laplae District (LP-AF). In addition, it was found that the average air surface temperature of the agroforestry in Nang Phaya Subdistrict, Tha Pla District, Uttaradit Province (NP-AF) was 28.07°C which was 0.75°C higher than that of the agroforestry in Mae Phun Subdistrict, Laplae District (LP-AF). Compared to the natural forest areas, all these 3 agroforestry systems showed no difference in the average near-surface air temperatures compared to the mixed deciduous forest. However, significant difference was found when all these 3 agroforestry systems were compared to the hill evergreen forest at a confidence level of 95%. In a study, the temperatures of soil and air in the agroforestry and the prominent plants affecting the yield of Arabica coffee bean in Tanzania were studied and it was found that there was a significant difference in soil and air temperature control among tree species ($p < 0.05$), in which the difference in soil and air temperature was 0.5-1.6 and 0.2-0.4°C, respectively. *G. robusta* can significantly control the soil and air temperature in both highlands and midlands ($p < 0.05$) compared to other plant species studied with the mean differences of 0.2-1.6 and 0.3–0.4°C, respectively [1]. In this study, it can be seen that the air surface temperature variation in the traditional agroforestry in Mae Phlu Subdistrict, Laplae District (LP-AF) tends to be similar to that of the natural forest on lower elevation. However, compared to the hill evergreen forest, it was found that the air surface temperatures of the agroforestry systems were lower due to the influence of elevation. However, considering the modern agroforestry in Nang Phaya Subdistrict, Tha Pla District, Uttaradit Province, which has similar elevation compared to the hill evergreen forest, the average air surface temperature was also higher. The context of agroforestry management affects physical and environmental factors such as climate, soil, or socio-economic [28]. The role of forest influences the adaptation and can mitigate the climate change impacts. It was reported that the agroforestry systems showed higher performance than monocultures [17, 21-24]. Similar to the research results obtained in previous studies on urban green space and agricultural protection forests, this difference is only pertinent for cooling [29]. Therefore, the importance of tree shade is related to the reflection and penetration of solar radiation [30], and the higher the coverage, the more significant the effect of crown coverage [30-31]. These agroforestry systems comprise diverse resilient species that have several uses, such as food, feed and goods for cash. Agroforestry systems also increase resilience of an agricultural production landscape and buffer risks arising from climate change [32]. Under severe climate events, resilient trees provide feed for cattle, shade for vegetables, and micro-climate for under-story plants [33].

Conclusions

Through nine months of continuous temperature data monitoring and field surveys, the present study addressed several questions about the benefit of agroforestry in the setting throughout the Eastern Phi Pan Nam Mountain Range Area, regarding climate regulation and ecosystem services. The study showed that agroforestry can decrease temperatures compared with the natural forest, with an August and October that was particularly pronounced in mixed deciduous forests. The effect of this decreased temperature is conducive to the promotion of decrease climate change and greenhouse gas absorption. However, the climate regulation function of agroforestry is usually overlooked in the current transformation of traditional agroforestry and the construction of new rural communities. Therefore, greater attention must be paid to the protection of forests by agroforestry planning, as well as to planning and technical system methods in the future.

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References

1. Rattan, L., David, K., David, O., Hansen, B., Ram, S., Theodosy, M., & Lars, O. E. (2016). *Climate change and multi-dimensional sustainability in African agriculture: climate change and sustainability in agriculture* (first ed., pp. 3-11). Springer International Publishing.
2. Nair, P. K. R. (1993). *An Introduction to agroforestry.* Kluwer Academic Publishers, Dordrecht, The Netherlands.
3. Torquebiau, E. F. (2000). A renewed perspective on agroforestry concepts and classification. *Comptes Rendus de L'academie des sciences. Serie III, Sciences de la viei, 323,* 1009-1017.
4. Nair, P. K. R. (1985). Classification of agroforestry systems. *Agroforestry Systems, 3*(2), 97-128.
5. Mbow, C., Smith, P., Skole, D., Duguma, L., & Bustamante, M. (2014). Achieving mitigation and adaptation to climate change through sustainable agroforestry practices in

Africa. *Current Opinion Environmental Sustainability, 6,* 8-14.

6. Eike, L., Roeland, K., Neil, I. H., & Konstantin, K. (2014). Agroforestry systems in a changing climate-challenges in projecting future performance. *Current Opinion Environmental Sustainability, 6,* 1-7.
7. Garrity, D. P., Akinnifesi, F. K., Ajayi, O. C., Weldesemayat, S. G., Mowo, J. G., Kalinganire, A., Larwanou, M., & Bayala, J. (2010). Evergreen agriculture: a robust approach to sustainable food security in Africa. *Food Security, 2,* 197-214.
8. Li, J., Song, C., & Cao, L. (2011) Impacts of landscape structure on surface urban heat islands: A case study of Shanghai, China. *Remote Sensing of Environment, 115*(12), 3249-3263.
9. Saneinejad, S., Moonen, P., & Carmeliet, J. (2014) Comparative assessment of various heat island mitigation measures. *Building and Environment, 73*(3), 162-170.
10. Declet-Barreto, J., Brazel, A. J., & Martin, C. A. (2013) Creating the park cool island in an inner-city neighborhood: heat mitigation strategy for Phoenix, AZ. *Urban Ecosystems, 16*(3), 617-635.
11. Doick, K., & Hutchings, T. (2013). Air temperature regulation by urban trees and green infrastructure. *CFA Newsletter, 60,* 14.
12. Gill, G., Phillippe, V., Just, V. W., & Laurance, J. (2018). Local tree knowledge can fast-track agroforestry recommendations for coffee smallholders along a climate gradient in Mount Elgon, Uganda. *Agroforestry Systems, 92,* 1625-1638.
13. Van Asten, P. J. A., Wairegi, L., Bagamba, F., & Drew, C. (2010). Factors driving fertilizer adoption in banana (Musa spp.) systems in Uganda. *Acta Horticulturae, 879,* 465-478.
14. Beer, J., Muschler, R., Kass, D., & Somarriba, E. (1998). Shade management in coffee and cacao plantations. *Agroforestry Systems, 38,* 139-164.
15. Campbell, BM., Thornton, P., Zougmore, R., Van Asten, P., & Lipper, J A. (2014). Sustainable intensification: What is its role in climate smart agriculture? *Current Opinion Environmental Sustainability 8,* 39-43.
16. Nzeyimana, I., Hartemink, A. E., & de Graaff, J. (2013) Coffee farming and soil management in Rwanda. Outlook on *Agriculture, 42*(1), 47-52.
17. Vaast, P., Bertrand, B., Perriot, J. J., Guyot, B., & Génard, M. (2006). Fruit thinning and shade improve bean characteristics and beverage quality of coffee (*Coffea arabica* L.) under optimal conditions. *Journal of The Science of Food Agriculture, 86*(2), 197-204.
18. Staver, C., Guharay, F., Monterroso, D., & Muschler, RG. (2001). Designing pest-suppressive multistrata perennial crop systems: shade-grown coffee in Central America. *Agroforestry Systems, 53*(2), 151-170.

19. Bos, M. M., Steffan-Dewenter, I., & Tscharntke, T. (2007). Shade tree management affects fruit abortion, insect pests and pathogens of cacao. *Agriculture, Ecosystems Environment, 120*(2-4), 201-205.
20. Tscharntke, T., Clough, Y., Bhagwat, S., Buchori, D., Faust, H., Hertel, D. & Wanger, TC. (2011) Multifunctional shade-tree management in tropical agroforestry landscapes: a review, *Journal of Applied Ecology, 48*(3), 619-629.
21. Cerdán, C. R., Rebolledo, M. C., Soto, G., Rapidel, B., & Sinclair, FL. (2012). Local knowledge of impacts of tree cover on ecosystem services in smallholder coffee production systems. *Agricultural Systems, 110,* 119-130.
22. Harvey, C., Chacón, M., Donatti, Cl., Garen, E., Hannah, L., Andrade, A., & Wollenberg, E. (2014). Climate-smart landscapes: opportunities and challenges for integrating adaptation and mitigation in tropical agriculture. *Conservative Letters, 7*(2), 77-90.
23. Rahn, E., Läderach, P., Baca, M., Cressy, C., Schroth, G., Rikxoort, H., & Shriver J. (2013). Climate change adaptation, mitigation and livelihood benefits in coffee production: where are the synergies? *Mitigation and Adaptation Strategies for Global Change, 19*(8), 1-19.
24. Vaast, P., Kanten, R., Siles, P., Dzib-Castillo, B., Franck, N., Harmand, J. M., & Genard, M. (2005). Shade: A key factor for coffee sustainability and quality. Proceedings of the 20th International Conference on Coffee Science, 11-15 October 2004, Bangalore, India, ASIC, (pp. 887-896) Association Scientifique Internationale du Café.
25. Liu, Q., Peng, P. H., Wang, Y. K., Xu, P., & Guo, YM. (2019). Microclimate regulation efficiency of the rural homegarden agroforestry system in the Western Sichuan Plain, China. *Journal of Mountain Science, 16*(3), 516-528.
26. Craparo, A. C. W., Van Asten, P. J. A., Läderach, P., Jassogne, L. T. P., & Grab S. W. (2015) Coffea arabica yields decline in Tanzania due to climate change: global implications. *Agricultural and Forest Meteorology, 207,* 1-10.
27. Davis, A. P., Gole, TW., Baena, S., & Moat, J. (2012). The impact of climate change on indigenous arabica coffee (*Coffea arabica*): predicting future trends and identifying priorities. *PLOS ONE, 7*(11), 10-14.
28. Lamond, G., Sandbrook, L., Gassner, A., & Sinclair, FL. (2019). Local knowledge of tree attributes underpins species selection on coffee farms. *Experimental Agriculture, 55* (S1), 35-49.
29. Zhuang, J. Y., Zhang, J. C., & Yang, Y. (2016). Effect of forest shelter-belt as a regional climate improver along the old course of the Yellow River, *China. Agroforest Systems, 6,* 393-401.

30. Georgi, N. J., & Zafiriadis, K. (2006).The impact of park trees on microclimate in urban areas. *Urban Ecosystems, 9*(3), 195-209.
31. Streiling, S., & Matzarakis, A. (2003). Influence of single and small clusters of trees on the bioclimate of a city: A case study. *Journal of Treeiculture, 29*(6), 309-316.
32. Quan, N., Minh, H. H., Ingrid, Ö., & Meine, V.N. (2013). Multipurpose agroforestry as a climate change resiliency option for farmers: an example of local adaptation in Vietnam. *Climatic Change, 117,* 241-257
33. Martius, C., Höfer, H., Garcia, M., Römbke, J., F?rster, B., & Hanagarth, W. (2004). Microclimate in agroforestry systems in central Amazonia: does canopy closure matter to soil organisms? *Agroforest Systems, 60,* 291-304.