Comparison of microclimate in various land-use systems in Jambi, Indonesia

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Vergleich von mikroklimatischen Bedingungen unterschiedlicher Landnutzungssysteme in Jambi, Indonesien

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Summary

Deforestation and land-use changes are ongoing problems for rain forests in Indonesia. They are converted into uniform rubber and oil palm plantations. Besides reducing the biodiversity of that region, the microclimatic conditions are affected. Few studies have been made investigating the effect of changes in land-use systems from forest to rubber and oil palm plantations on the microclimate. This study was carried out in one of the most deforested regions of Indonesia, Jambi. Microclimatic conditions on a daily, weekly and seasonal basis across four land-use systems were characterized. The effect of the strong ENSO event in 2015 on the microclimate was investigated, while canopy openness and microclimatic variables were related to each other, using the linear regression method.

The analysis is based on microclimatic measurements e.g. air temperature, relative humidity, soil moisture and soil temperature taken in four land-use systems, forest (F), jungle rubber (J), oil palm (O) and rubber (R), in two different landscapes, Harapan and Bukit. The data set covers a period of approximately three years from April 2013 to March 2016.

The results showed that mean air temperature, soil temperature, relative humidity and vapour pressure deficit differed significantly between four land-use systems whereas the mean soil moisture differed significantly between two landscapes. Air temperature, vapour pressure deficit and soil temperature were highest in oil palm and rubber plantations whereas lowest in forest and jungle rubber.

After the ENSO of 2015, a significant increase in mean air temperature, soil temperature and vapour pressure deficit but a decrease in relative air humidity and soil moisture in all four land-use systems was found. However, among the increase of air temperature and the decrease of air humidity, the effect of ENSO was highest in forest and jungle rubber compared to rubber and oil palm plantations. Furthermore, air temperature, soil temperature and vapour pressure deficit were positively correlated with canopy openness whereas relative humidity was negatively related with canopy openness.

In conclusion, conversion of forest to rubber and oil palm plantations has led to warmer and drier microclimatic conditions than before. In addition to this, the effect of the ENSO event of 2015 was noticed in all four land-use systems with warmer and drier conditions than in 2013 and 2014.

Zusammenfassung

Abholzung und Landnutzungsänderungen sind große Probleme für Indonesiens Regenwälder. Der Regenwald wird in gleichmäßige Gummibaum- und Ölpalmenplantagen umgewandelt. Während die Biodiversität in der jeweiligen Region reduziert wird, ist der Einfluss auf das Mikroklima nur bedingt abzuschätzen. Nur wenige Studien befassten sich bisher mit dem Effekt von Landnutzungsänderungen von Regenwald zu Olpalmen- und Gummibaumplantagen auf das Mikroklima.

Die vorliegende Arbeit wurde in der gefährdetsten Region Indonesiens, Jambi, durchgeführt und befasst sich mit der Charakterisierung der mikroklimatischen Bedingungen von vier Landnutzungssystemen auf Basis von Tages-, Wochen und Saisonalen Mitteln. Weiterhin wurde der Effekt des ENSO Ereignisses 2015 auf das Mikroklima in den Analysen berücksichtigt und der Bestandesbedeckungsgrad mit mikrometeorologischen Parametern korreliert, durch zur Hilfenahme linearer Regression. Die Analysen basieren auf Messungen von Lufttemperatur, relativer Luft- und Bodenfeuchte und -temperatur in zwei unterschiedlichen Landschaften, Harapan und Bukit, inmitten der vier zentralen Messpunkte der Landnutzungssysteme Wald (F), Urwald Gummibaum (J), Ölpalm- (O) und Gummibaumplantagen (R). Der Datensatz umfasst einen Zeitraum von April 2013 bis März 2016.

Die Ergebnisse zeigen, dass die mittlere Luft- und Bodentemperatur, sowie die relative Feuchte und das Dampfdruckdefizit unter den vier Landnutzungssystemen mit hoher Signifikanz variieren, während die mittlere Bodenfeuchte nur signifikante Unterschiede zwischen den beiden Landschaften aufweist. Höchste Werte der Lufttemperatur, der Bodenfeuchte und des Dampfdruckdefizits wurden in Ölpalmen- und Gummibaumplantagen gefunden, während sie im Wald und Urwald-Gummibaum am geringsten sind.

Bei Berücksichtigung des ENSO Ereignisses 2015 wurde ein signifikanter Anstieg der mittleren Luft- und Bodentemperatur und des Dampfdruckdefizits und eine damit verbundene Abnahme der Luft- und Bodenfeuchte in den vier Landnutzungssystemen gefunden. Die stärkste Zunahme der Lufttemperatur und somit Abnahme der relativen Feuchte zeigte sich im Wald und Urwald-Gummibaum.

Die Korrelation zwischen Lufttemperatur, Bodenfeuchte und Dampfdruckdefizit und dem Bestandesbedeckungsgrad ist positiv, wobei die relative Feuchte eine negative Korrelation aufweist.

Zusammenfassend zeigte sich, dass die Umwandlung von Regenwald zu Gummibaum- und Ölpalmenplantagen zu wärmeren und trockeneren Bedingungen führt. Dieser Effekt wurde durch das ENSO Ereignis 2015 zusätzlich verstärkt, verglichen mit den Jahren 2013 und 2014 war dieses Jahr überdurchschnittliche warm und trocken.

Acknowledgement

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1. Introduction

1.1 Deforestation and land use change

Almost 4.0×10^7 km^2 of the earth's surface is covered by forest, which accounts for 31% of the world terrestrial land surface (FAO 2012). Forests deliver social, economic and ecological benefits to humans, including wood production, recreation, climate regulation and biodiversity preservation (FAO 2012). Globally, more than 200 million people including many indigenous groups of people, depend directly on forests for their basic needs (Brack 2014).

Furthermore, forests are a significant carbon sink at the global scale. It is estimated that sustainable global forest management could store about 1 Gt of carbon per year (Ni et al. 2016). Nevertheless, these forest resources are under serious threat due to deforestation and land-use change.

Deforestation or forest loss is the conversion of forested lands to non-forested lands such as grassland, agricultural land, plantation area, urban land etc. Between 1980 and 2012, more than 150 million hectares of tropical forests were destroyed (Hansen et al. 2013). From 2000 to 2012, the forest cover loss of Indonesia accounted for 6.02 million hectares (Margono et al. 2014). Moreover, Sumatra island alone lost about five hundred and fifty thousand hectares of forest per year between 1990 and 2007 (Laumonier et al. 2010).

In Sumatra, the transformation of tropical forests to traditional agroforestry systems started in the early 1900's, where rubber trees were inter-cropped within the natural vegetation (Gouyon et al. 1993). This form of agricultural practice was later converted into monoculture plantations by a complete removal of forest stands with cash crops such as rubber and oil palm (Fitzherbert et al. 2008). The area of rubber plantations augmented from 1.8 million hectares in 1990 to 3.5 million hectares in 2013 (FAOSTAT 2016). Cultivation of oil palm started in 1911 on the east coast of Sumatra under Dutch administration (Corley & Tinker 2003). Even though it was introduced for decorative purposes, the economic benefits of oil palm were realized and it was soon transformed into one of the most demanding cash crops in the region. There was a dramatic increase in the oil palm cultivation area since its development, from seven hundred thousand hectares in 1990 to seven million hectares in 2013 (FAOSTAT 2016).

1.2 Microclimate and its sensitivity to land-use change

Microclimate can be defined as the climatic condition of a small region that might be varying within a short distance of few centimeters and meters (Adams 2010b). Air temperature, atmospheric humidity, soil temperature, direction and speed of the wind and soil moisture are some of the variables that are generally used to understand the microclimatic conditions of a particular region. Topography and vegetation are the strong governing factors for the differences in climate on the micro-scale (Hardwick et al. 2015). The topographical factors affecting the climate of an area on micro-scale level include physiographic settings of an area such as elevation, slope and aspect (Dobrowski 2011).

Trees can influence local climate through various mechanisms. The proportion of the reflected solar radiation from a surface and the total incoming solar radiation penetrating the surface is known as albedo of a surface (Sanderson et al. 2012). The darker the forest surface the higher the absorption of solar radiation will be, while the reflection of solar radiation is reduced. Furthermore, the forest has a low albedo which means that only a small quantity of the incoming solar energy is reflected and thus a high amount of energy is absorbed (Betts & Ball 1997).

The second important mechanism through which trees can influence local climate is evapotranspiration which is a combination of transpiration from tree leaves and evaporation from soil water and intercepted water from the leaves. Trees uptake water from the soil through their deep rooting system and release it into the atmosphere in the form of water vapour (Randow et al. 2004). This process of evapotranspiration plays an important role in atmospheric and surface cooling which ultimately influences local weather and climate. Another important mechanism by which trees influence local climate is through their roughness. Big trunks and branches carry heat and water vapour upwards, which results in cooling of the area (Adams 2010a).

Anthropogenic activities such as the expansion of forested land for agriculture, land-use change, deforestation and natural disturbances can alter the trends of air temperature, humidity, soil moisture and wind speed (Chen et al. 1999). Land use changes and deforestation will result in a reduction of the surface roughness and leaf area index which will increase the surface albedo and decrease the evapotranspiration. This will eventually increase the local temperature because not much latent heat of evaporation will be taken up due to the removal of vegetation (Adams 2010a). Alkama & Cescatti (2016) also reported that deforestation magnifies the diurnal temperature range and increase the average and maximum air temperature.

1.3 El Niño Southern Oscillation (ENSO)

The El Niño Southern Oscillation (ENSO) is an interaction of ocean and atmosphere which is characterized by unpredictability in inter-annual sea surface temperature (SST), sea surface pressure and atmospheric circulation across the equatorial Pacific Ocean (Trenberth 1997). ENSO events create warm conditions by replacing cool sea surface temperature with warm sea surface temperature. Warming in the oceans gets diffused all over the area by the wind caused by ENSO events. This leads to an increase in the surface temperature in tropics and changes in atmospheric pressures, wind patterns and rainfall. ENSO events normally lead to warmer and drier conditions which will cause severe drought in an area (Harger 1995; Wich & Schaik 2000)

After 1970 when the satellite data became accessible, ENSO events have been reported to be regular, with an average time between events of about four years (McGregor & Nieuwolt 1998). Among the most recent ENSO events after 1970, ENSO events of 1982, 1997 and 2015 were supposed to be very strong (Glantz et al. 1991; Varotsos et al. 2016). Furthermore, among those three ENSO events, the ENSO of 2015 could be the second strongest ENSO event reported so far after 1997 (Varotsos et al. 2016).

1.4 Research objectives and hypotheses

The conversion and clearance of the forest to plantation area are anticipated to disturb not only biodiversity and carbon storage capacity of the forest but also the biophysical environments such as air and surface temperature, surface albedo, air humidity, and soil moisture. Although the effects of land-use change on many ecological characteristics and processes (Guo & Gifford 2002; Dayamba et al. 2016; Zerbo et al. 2016) have been addressed, the effects of land-use change on the microclimate remain poorly understood. Some studies have shown that mean maximum temperature in logged forest and oil palm plantations are 2.5 °C and 6.5 °C greater than primary forest, respectively (Hardwick et al.

2015). During daytime hours, oil palm plantations were 2.8 °C warmer and drier than natural vegetation (Luskin & Potts 2011). Jiang & Wang (2003) stated that replacement of natural forest with rubber plantations had no effect on the local rainfall of the area. However, there are no previous studies on microclimatic effects of the conversion of natural forest to rubber plantations. Thus, it is necessary to understand how microclimate varies with the change in land-use systems in a tropical landscape from forest to oil palm and rubber plantations. To address this question, this research was focused on the comparison of the microclimatic condition in four land-use systems, namely forest, jungle rubber, oil palm and rubber in Jambi province in Sumatra/Indonesia.

Furthermore, the ENSO is expected to create hotter and drier conditions in an area. The effect of ENSO is expected to be more severe in the land-use systems with more open canopies than in land-use systems with closed canopies (Curran & Paoli 1999; Chappell et al. 2001). But there is a lack of knowledge about the climatic impacts of ENSO on various land-use systems such as forest, rubber and oil palm plantations. Thus, we assessed the climatic impacts of the strong ENSO event of 2015 across four land-use systems, namely forest, jungle rubber, oil palm and rubber.

The objectives of this study were to:

- Quantify daily, weekly and seasonal climatic conditions across four land-use systems
- Quantify the effects of ENSO across four land-use systems
- Investigate the relationship between canopy openness and microclimatic variables

Based on the above mentioned research objectives the following hypotheses were formed:

- Average microclimate will change in response to changes in land-use. With increasing canopy openness, air temperature and soil temperature increase, while air humidity and soil moisture decrease.
- Land-use systems with higher canopy opening will have higher diurnal and seasonal variability in air temperature and air humidity.
- The effect of ENSO induced drought and high temperatures on microclimate are less pronounced in primary forests than in rubber and oil palm plantations.

2. Methodology

2.1 Study area and design

The study was carried out in Jambi province (Figure 1). Jambi is one of the 34 provinces of Indonesia with an area of about fifty thousand square kilometers. The Jambi province has a tropical humid climate with a mean annual temperature and a mean annual precipitation of 26.7 ± 0.2°C and 2235 ± 381 mm, respectively. The annual weather is characterized by a rainy season which lasts from October to April and a dry period during July-August (Drescher et al. 2016). The weekly averages of air temperature, air humidity, vapour pressure deficit (VPD), precipitation, soil temperature and soil moisture outside the canopy of the study area are given in Figure 2.

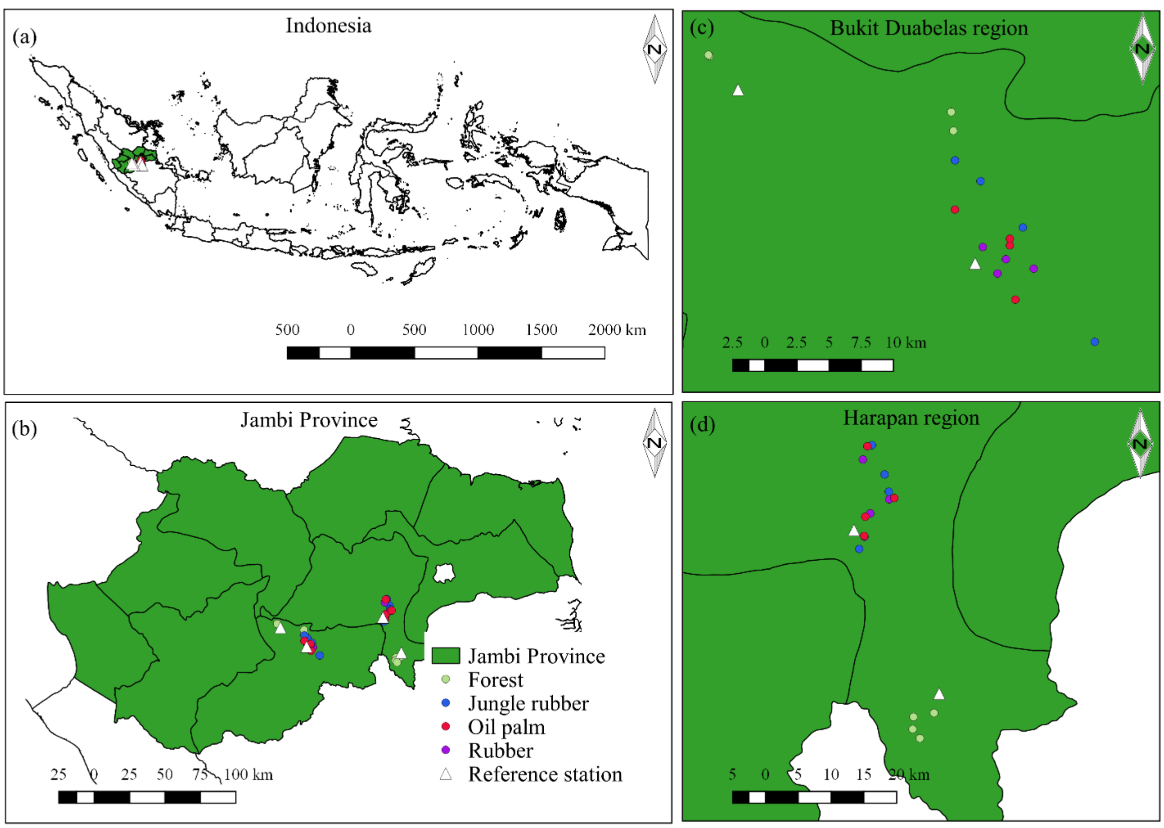


Figure 1: Location of the study site (a) Indonesia with Jambi province, (b) Jambi province, (c) core plot design in Bukit Duabelas region and (d) core plot design in Harapan region.

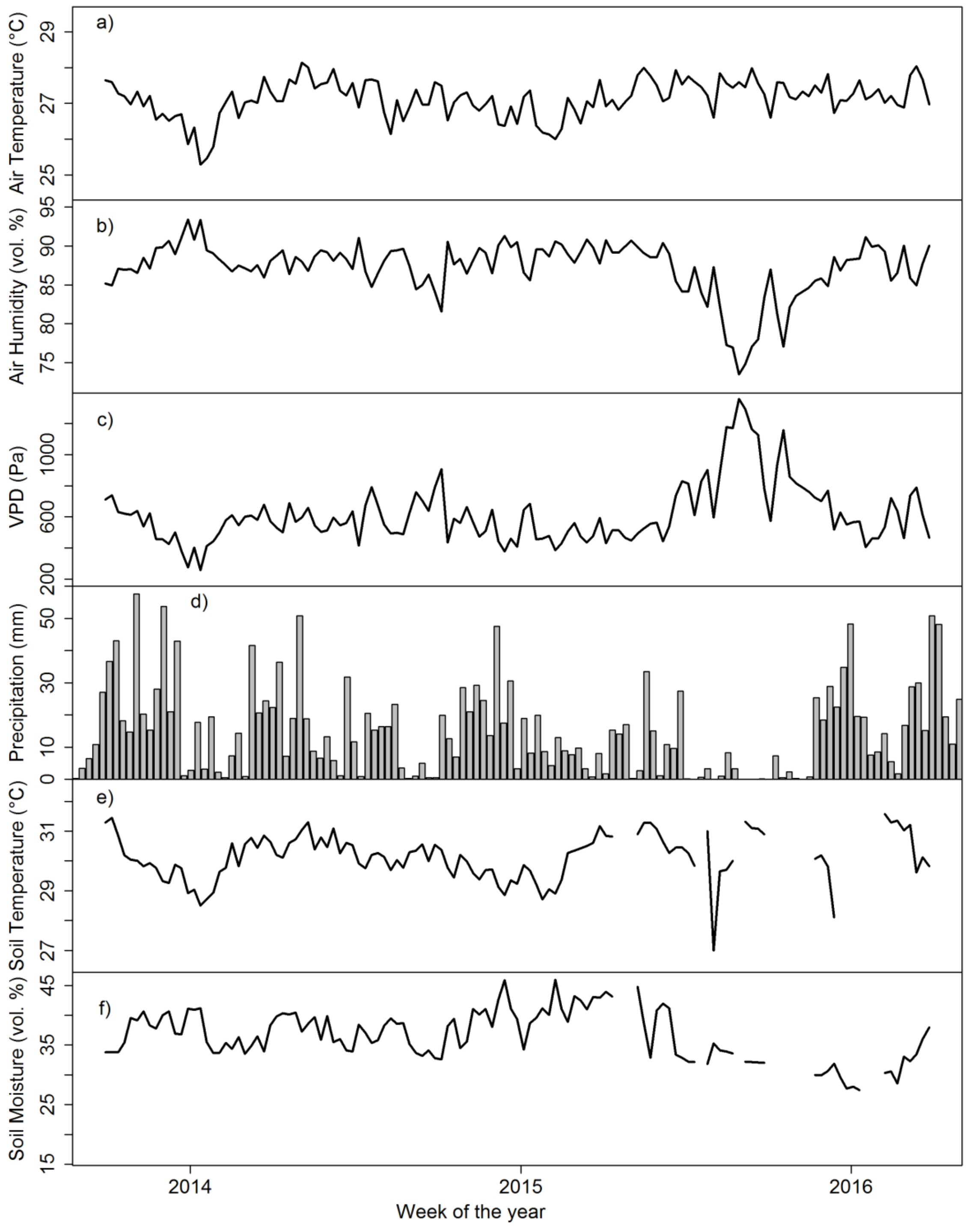


Figure 2: The trends for weekly means of the open areas at two meter of (a) air temperature, (b) air humidity, (c) vapour pressure deficit, (d) precipitation, (e) soil temperature and (f) soil moisture from June 2013 to March 2016. For precipitation, bars represent the sum of the weekly precipitation.

The study was carried out in two different landscapes: the Harapan (HR) and Bukit Duabelas region (BD). Harapan is situated around 50 km south-west of Jambi city at an altitude of 70 m above sea level and its soil is loam Acrisol. Whereas Bukit Duabelas is situated around 90 km west of Jambi city at an altitude of 75 m above sea level and its soil is clay Acrisol.

In both of the landscapes four different land-use systems were selected namely forest (lowland rainforest with natural vegetation - F), jungle rubber (the agroforestry systems with rubber and other tree species - J), rubber (pure monoculture plantations of rubber - R) and oil palm (pure monoculture plantations of oil palm - O) (Drescher et al. 2016). During the time of the plot selection in 2012, the age of rubber plantations varied between 7 and 16 years whereas the age of oil palm varied from 8 to 15 years (Drescher et al. 2016). In each of the landscapes, 4 core plots per land-use system were established, resulting in 16 plots per landscape and a total number of 32 plots. The minimum distance between plots is 300 meters. The two different landscapes with the distribution of the core plots are presented in Figure 1. Similarly, the land-use types with the geographical coordinates of the core plots and meteo-stations of the study area are given in Appendix 1.

2.2 Materials and methods

Meteorological stations were installed in each of the core plots. The meteorological stations were equipped with thermohygrometers (Galltec Mella, Bondorf, Germany) at a height of 2 meters from ground level to measure air temperature (°C) and relative air humidity (vol. %). Similarly, soil moisture probes (IMKO Trime-PICO, Ettlingen, Germany) were installed at a depth of 30 cm for measuring soil temperature (°C) and soil moisture (vol. %) (Drescher et al. 2016). Hourly monitoring of all the four climate variables was done and stored using 16-GPRS data logger (Drescher et al. 2016).

Additionally, four meteorological reference stations, two in each landscape, were mounted in open areas to perform measurements on global radiation (CMP3 pyranometer, Kipp & Zonen, Delft, The Netherlands), rainfall (two precipitation transmitter Thies Clima, Göttingen, Germany), soil heat flux (model HFP01, Hukseflux, Delft, The Netherlands), wind speed (with a 3-cup anemometer, Thies Clima, Göttingen, Germany) and wind direction (Thies Clima, Göttingen, Germany). In addition to this, two thermohygrometers (Thies Clima, Göttingen, Germany) were also installed in four meteorological stations at 0.5m and

2m height on each reference stations to perform measurement of air temperature and relative humidity. The data for mean canopy openness were used from Drescher et al. (2016). The hourly climate data, collected from April 2013 to March 2016 in 32 plots was used for the analysis.

2.3 Data analysis

Before commencing data analysis, a quality check of the measured climate values was carried out. Considering the tropical climate, a standard set of norms for upper and lower limits for all the climate variables were formed for checking the quality of the collected data. See Table 1 for upper and lower limits.

Table 1: Ranges of the climate variables defined for quality check of the collected data.

Climate Variables	**Lower limit**	**Upper limit**
Air temperature (°C)	10	40
Air humidity (vol. %)	10	100
Soil temperature (°C)	10	40
Soil moisture (vol. %)	10	60

Vapour pressure deficit (VPD) was calculated for each measurement of air temperature and air humidity as the difference between saturated water vapour pressure (e_s) and actual water vapour partial pressure (e) as shown in eq. 1.

$$\mathrm{VPD} = e_s - e \qquad (1)$$

The actual water vapour partial pressure (e) was then estimated using eq. 2.

$$\text{Relative humidity} = \frac{e}{e_s} \times 100 \qquad (2)$$

And the saturated water vapour pressure (e_s) was calculated from the measured air temperature (T) using Bolton (1980) shown in eq. 3.

$$e_s = (0.6112\ \text{kpa}) \times exp\left[\frac{17.67 \times (T - 273.16)}{T - 29.66}\right] \qquad (3)$$

Daily values of each measured climate variables were calculated from the hourly measurement for all plots. Overall means of each climate variables were calculated for all plots to calculate the overall mean of each land-use systems. Overall means for each land-use systems from daily maximum and minimum as well as daily standard deviations of each climate variable were also estimated. The weekly mean of climate variables was calculated for each land-use type. The mean diurnal cycles were estimated for each land-use system and were compared with each other. The rainfall data collected from reference meteorological stations were used to identify those months where the effects of ENSO were more pronounced. The overall mean and mean diurnal cycles of those months for all three years (2013, 2014 and 2015), were calculated for all four land-use systems.

The statistical significance of differences in means of measured climate variables across four different land-use systems was tested using the one-way analysis of variance (ANOVA) with F-test. Further, the Tukey honest significant difference (HSD) test was used to find out which land-use systems significantly differed with each other. The same approach was used to test the significance of differences in means of measured microclimatic variables before and after ENSO period. Linear regression was used to test the relationship between mean canopy openness and climate variables. Furthermore, data processing and analysis were done using R version 3.2.5 (R Core Team, 2016-04-14).

3. Results

3.1 Overall means of measured climate variables across four land-use systems

The overall daily means of five different climate variables across four different land-use systems are given in Table 2 and Figure 3. The mean air temperature and soil temperature during the study period were highest in oil palm, followed by rubber, jungle rubber and forest. Similarly, Vapour pressure deficit showed the similar pattern with highest in oil palm, followed by rubber, jungle rubber and forest. However, relative air humidity followed the opposite pattern with highest in the forest, followed by jungle rubber, rubber and oil palm plantations (Figure 3). Soil moisture was similar in all four land-use systems.

Air temperature, air humidity, vapour pressure deficit and soil moisture between landscapes were similar except for soil moisture. Soil moisture was recorded higher in Bukit region than in Harapan region (Figure 4).

Table 2: Overall mean values (and the margin of error at 95% confidence interval) of the measured climate variables across four different land-use systems from April 2013 to March 2016.

Land-use (n = 8)	**Air temperature (°C)**	**Air humidity (vol. %)**	**Vapour pressure deficit (Pa)**	**Soil temperature (°C)**	**Soil moisture (vol. %)**
Forest	24.80 (± 0.11)	95.57 (± 1.03)	166.99 (± 38.42)	24.99 (± 0.72)	29.71 (± 2.49)
Jungle rubber	25.18 (± 0.09)	93.29 (± 0.80)	269.76 (± 32.89)	25.55 (± 0.19)	32.25 (± 2.29)
Oil palm	25.53 (± 0.12)	90.72 (± 0.79)	386.95 (± 43.09)	26.12 (± 0.23)	34.42 (± 1.20)
Rubber	25.45 (± 0.19)	91.29 (± 0.80)	355.18 (± 37.95)	26.09 (± 0.70)	34.12 (± 4.15)

The mean values of air temperature, air humidity, vapour pressure deficit and soil temperature of four land-use systems differed significantly with each other (ANOVA F-test, Table 3). There was a significant difference in the mean values of air temperature, air humidity and vapour pressure deficit of forest with jungle rubber, oil palm and rubber plantations (Tukey HSD, Figure 5). Similarly, the mean values of air temperature, air humidity and vapour pressure deficit of jungle rubber also differed significantly with oil palm and rubber plantations. But there was no significant difference in the mean value of air temperature, air humidity and vapour pressure deficit between oil palm and rubber plantations. Accordingly, the mean value of soil temperature of the forest only differed significantly with oil palm and rubber. On the other hand, there was no significant difference in the mean values of air temperature, air humidity, vapour pressure deficit and soil temperature between two landscapes Harapan and Bukit. However, the mean value of soil moisture differed significantly between landscapes. The F-statistic and p-value of ANOVA test are given in Table 3 and the results from the Tukey HSD test are provided in Figure 5.

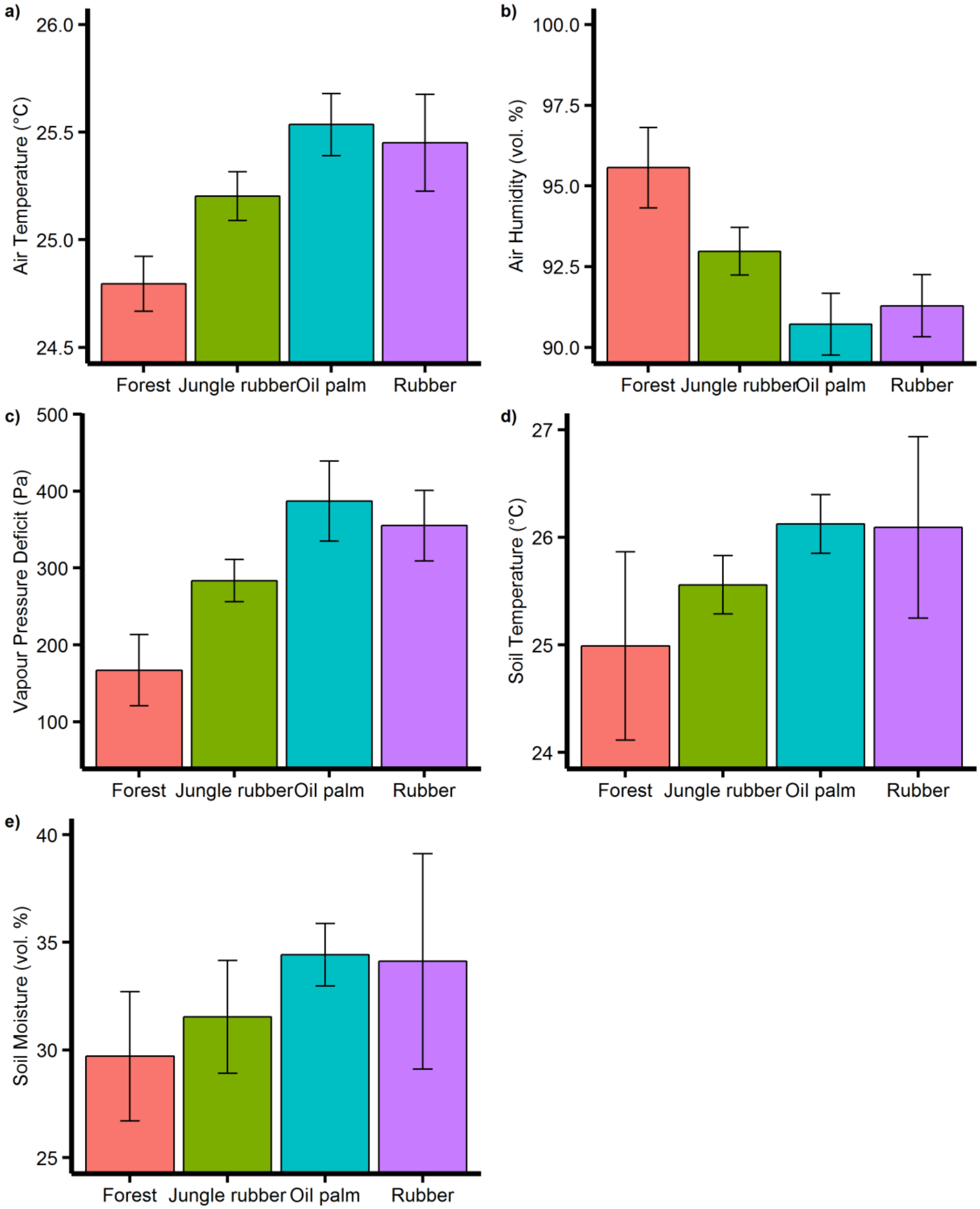


Figure 3: The overall mean of the daily values of a) air temperature, b) relative air humidity, c) vapour pressure deficit, d) soil temperature and e) soil moisture across the four land-use systems. Lines over bars represent the margin of error at 95% confidence interval.

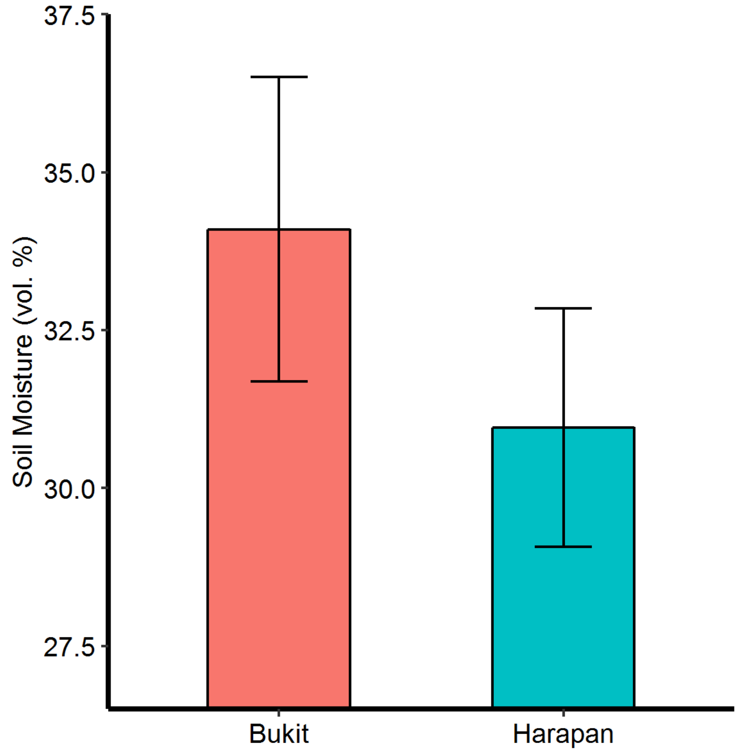


Figure 4: The overall mean of soil moisture between two landscapes. Lines over bars represent the margin of error at 95% confidence interval.

Table 3: F-statistic and p-values of ANOVA test.

Effect	**Climate Variable**	**F - statistic**	**p-value**
Landuse	Air temperature	24.78	< 0.001
Landscape		0.20	0.660
Landuse	Air Humidity	24.94	< 0.001
Landscape		0.21	0.654
Landuse	VPD	25.45	< 0.001
Landscape		0.29	0.597
Landuse	Soil temperature	4.01	0.017
Landscape		0.04	0.851
Landuse	Soil Moisture	2.40	0.089
Landscape		5.77	0.023

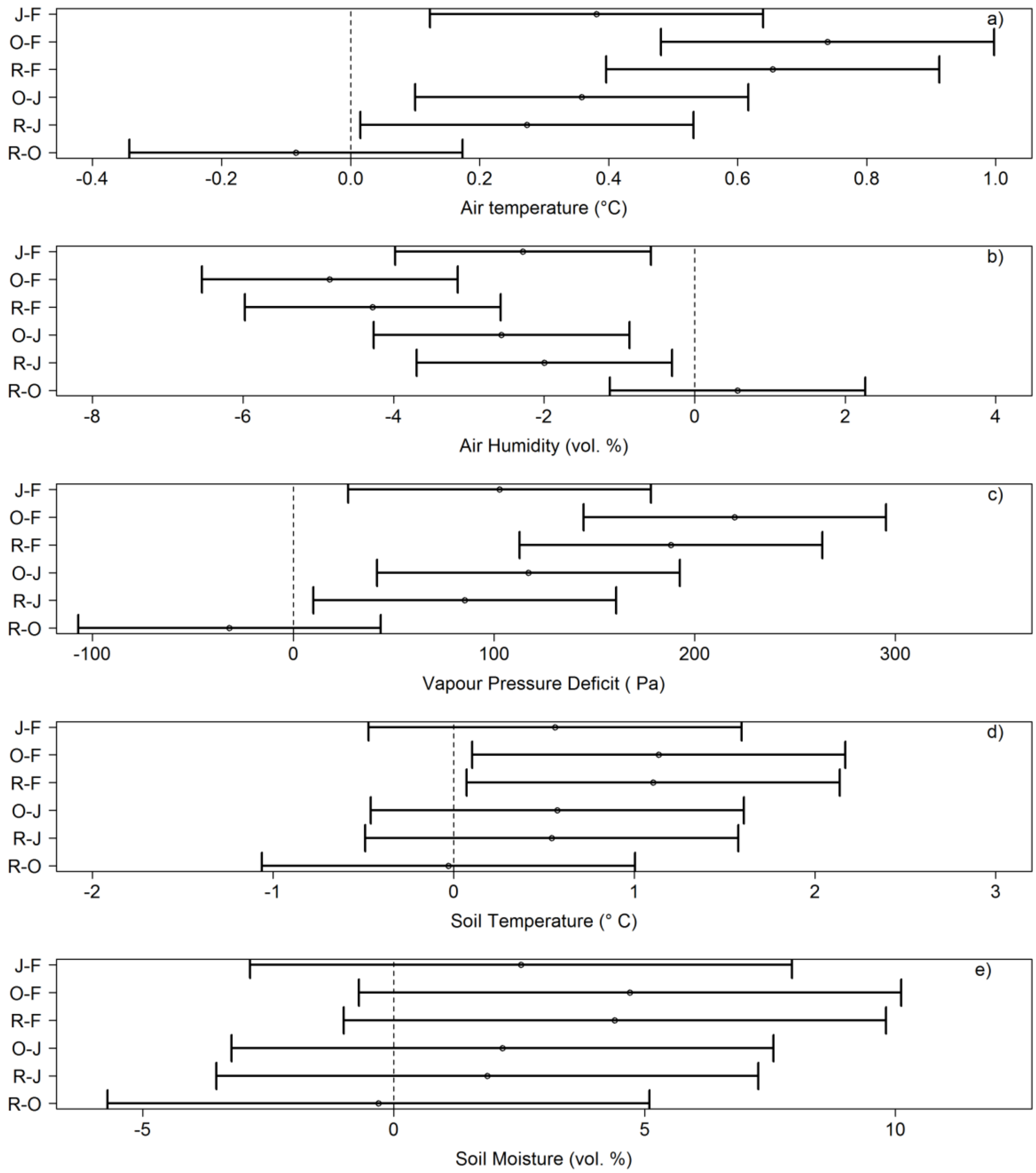


Figure 5: Result from the Tukey HSD test with land-use systems differing with each other in the mean value of a) air temperature, b) air humidity, c) vapour pressure deficit, d) soil temperature and e) soil moisture.

3.1.1 Overall means of maximum/minimum of measured climate variables

The overall mean daily maximum and minimum of five different climate variables across four land-use systems are given in Table 4 and Table 5 respectively. The mean daily maximum air temperature, vapour pressure deficit and soil temperature were highest in rubber and lowest in the forest while mean daily minimum relative air humidity was 12 (vol. %) higher in the forest than in rubber. The mean minimum values of air temperature, vapour pressure deficit, soil temperature and maximum air humidity were almost similar for all four land-use systems.

Table 4: Overall mean values of the daily maximum (and the margin of error at 95% confidence interval) of measured climate variables across four different land-use systems.

Land-use (n=8)	**Air temperature (°C)**	**Air humidity (Vol. %)**	**Vapour pressure deficit (Pa)**	**Soil moisture (Vol. %)**	**Soil temperature (°C)**
Forest	28.30 (± 0.17)	99.93 (± 0.06)	712.58 (± 100.25)	30.93 (± 2.58)	25.17 (± 0.70)
Jungle rubber	29.83 (± 0.29)	99.97 (± 0.02)	1094.05 (± 85.52)	33.40 (± 2.28)	25.71 (± 0.18)
Oil palm	30.60 (± 0.18)	99.90 (± 0.07)	1371.52 (± 71.43)	35.57 (± 1.14)	26.36 (± 0.26)
Rubber	30.75 (± 0.38)	99.93 (± 0.09)	1338.64 (± 95.21)	35.48 (± 4.29)	26.38 (± 0.72)

Table 5: Overall mean values of the daily minimum (and the margin of error at 95% confidence interval) of measured climate variables across four different land-use systems.

Land-use (n=8)	**Air temperature (°C)**	**Air humidity (Vol. %)**	**Vapour pressure deficit (Pa)**	**Soil moisture (Vol. %)**	**Soil temperature (°C)**
Forest	22.37 (± 0.05)	81.92 (± 2.45)	2.90 (± 2.26)	29.05 (± 2.51)	24.82 (± 0.74)
Jungle rubber	22.16 (± 0.10)	74.47 (± 1.66)	2.19 (± 1.70)	31.58 (± 2.33)	25.40 (± 0.20)
Oil palm	22.26 (± 0.10)	68.93 (± 1.53)	14.95 (± 19.53)	33.79 (± 1.21)	25.91 (± 0.20)
Rubber	22.11 (± 0.12)	69.75 (± 1.69)	5.70 (± 5.51)	33.39 (± 4.07)	25.84 (± 0.69)

The observed difference between the land-use systems in mean maximum air temperature, vapour pressure deficit and soil temperature was significant (ANOVA Table 6). Also, the observed difference in mean minimum air humidity was significant (ANOVA Table 6). The F-statistic and p-value of ANOVA test are given in Table 6. The mean maximum values of air temperature and vapour pressure deficit of forest differed significantly from the mean value of jungle rubber, oil palm and rubber plantations (Tukey HSD Appendix 2). Furthermore, the mean value of maximum air temperature and vapour pressure deficit of jungle rubber differed significantly with oil palm and rubber plantations. But there was no significant difference in the mean maximum values of air temperature and vapour pressure deficit of oil palm and rubber plantations. Accordingly, the mean minimum values of relative air humidity of forest also differed significantly from the mean values of jungle rubber, oil palm and rubber plantations. Moreover, the mean minimum values of jungle rubber differed significantly from the mean values of oil palm and rubber plantations. The results from Tukey HSD test showing land-use systems having a significant difference in means of maximum and minimum values of measured climatic variables are given in Appendix 2 and Appendix 3.

Table 6: F-statistic and p-values of ANOVA test.

Effect (Landuse, n = 8)	**Climate Variable**	**F - statistic**	**p-value**
Maximum	Air temperature	72.63	< 0.001
Minimum		3.28	0.035
Maximum	Air Humidity	1.21	0.325
Minimum		40.91	< 0.001
Maximum	VPD	45.06	< 0.001
Minimum		1.26	0.306
Maximum	Soil temperature	4.68	0.009
Minimum		3.47	0.029
Maximum	Soil Moisture	2.49	0.081
Minimum		2.58	0.074

3.1.2 Overall means of the difference between land-use systems and reference stations

The overall means of the difference between land-use systems and reference stations (outside the canopy) of the five climate variables across the four land-use systems are given in Table 7 and Figure 6. All four land-use systems were cooler and less dry than the reference stations. The difference of air temperature and vapour pressure deficit of the reference stations was smaller in forest and jungle rubber but greater in oil palm and rubber plantations. The differences in air humidity were greater in forest and jungle rubber while smaller in rubber and oil palm plantations.

Table 7: Overall mean values (and the margin of error at 95% confidence interval) of the difference between land-use systems and reference stations of measured climate variables across four different land-use systems.

Land-use (n=8)	**Air temperature (°C)**	**Air humidity (Vol. %)**	**Vapour pressure deficit (Pa)**	**Soil moisture (Vol. %)**	**Soil temperature (°C)**
Forest	- 2.41 (± 0.13)	7.80 (± 1.20)	- 417.13 (± 47.67)	- 6.32 (±2.11)	- 5.41 (± 0.52)
Jungle rubber	- 1.97 (± 0.11)	5.44 (± 0.91)	- 308.45 (± 38.54)	- 4.89 (±2.85)	- 4.91 (± 0.16)
Oil palm	- 1.62 (± 0.11)	2.79 (± 0.66)	- 194.96 (± 27.69)	- 2.12 (±1.68)	- 4.23 (± 0.31)
Rubber	- 1.68 (± 0.13)	3.50 (± 0.64)	- 220.09 (± 25.60)	- 3.03 (±4.27)	- 4.08 (± 0.62)

Further, the ANOVA test revealed that the observed difference between the daily mean values of the land-use systems and the reference stations of air temperature, relative air humidity, vapour pressure deficit and soil temperature across four land-use systems was significant (F-test ANOVA, Table 8). According to Tukey HSD test, forest differed significantly from jungle rubber, oil palm and rubber plantations. Similarly, jungle rubber also differed significantly with oil palm and rubber plantations. The graphs from Tukey HSD test showing land-use systems having a significant difference in means of the difference between land-use systems and reference stations of measured climatic variables are given in Appendix 4.

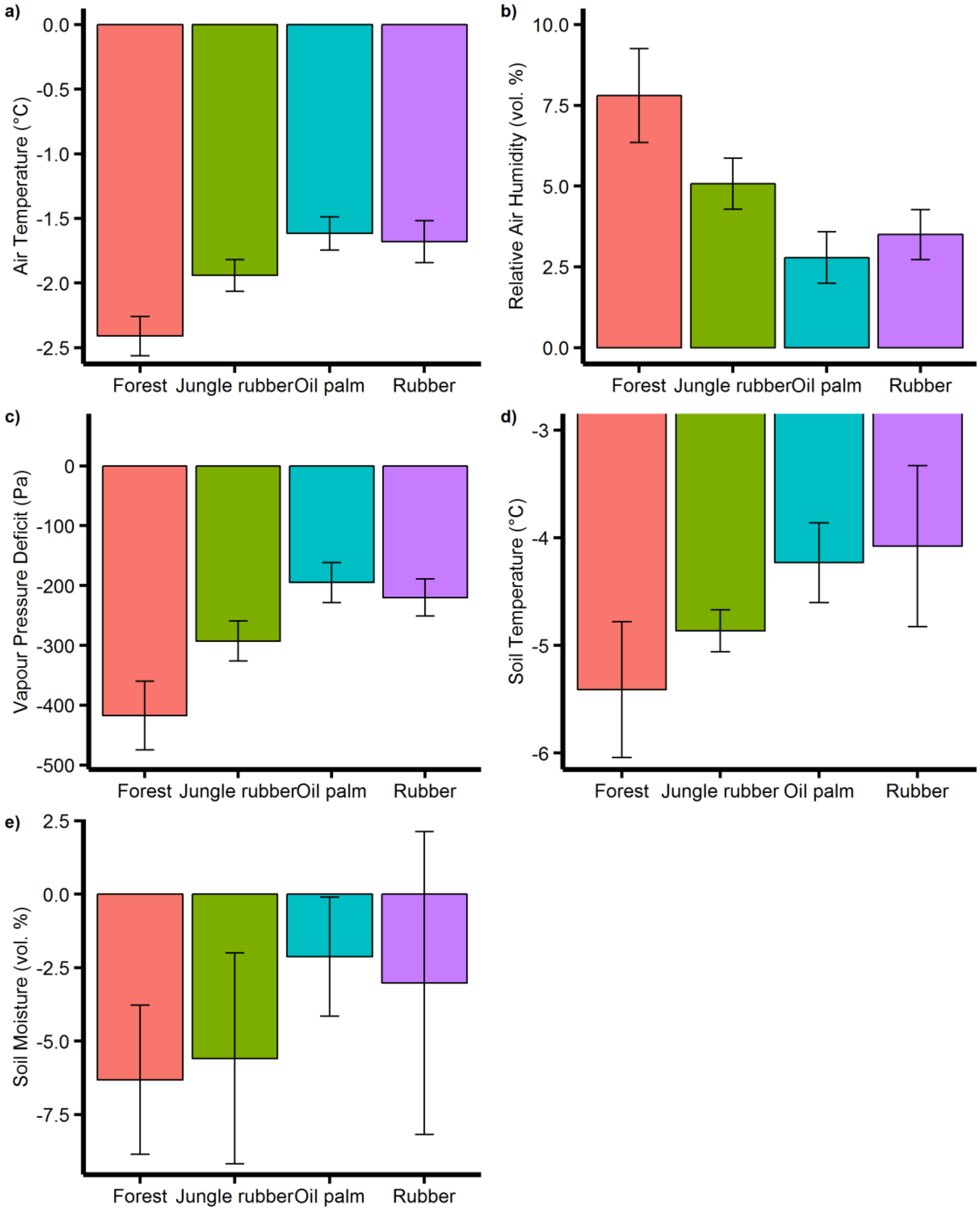


Figure 6: The overall mean of the difference between land-use systems and reference stations of a) air temperature, b) relative air humidity, c) vapour pressure deficit, d) soil temperature and e) soil moisture. Lines over bars represent the margin of error at 95% confidence interval.

Table 8: F-statistic and p-values of ANOVA test.

Effect	Climate Variable	F - statistic	p-value
Landuse	Air temperature	35.39	< 0.001
Landuse	Air Humidity	24.93	< 0.001
Landuse	VPD	29.99	< 0.001
Landuse	Soil temperature	7.57	< 0.001
Landuse	Soil Moisture	1.62	0.218

3.2 Weekly mean

The weekly mean of air temperature, soil temperature and vapour pressure deficit showed similar trends across all land-use systems (Figure 7). It was clearly observed that peaks with values repeatedly increasing during dry months and decreasing during rainy seasons. The weekly mean air temperature, soil temperature and vapour pressure deficit were higher in monoculture plantations (rubber and oil palm) but lower in forest and jungle rubber during the entire study period.

Moreover, air temperature and soil temperature were around 25 °C in 2013 and 2014 in rubber and oil palm plantations. In 2015, air temperature and soil temperature increased in both land-use systems and reached up to 27 °C during the dry season. That was not the case during the dry seasons of 2013 and 2014. In the dry season, forest experienced a similar increase in air temperature from around 24 °C in 2013 and 2014 to 25.5 °C in 2015. During the dry months (April - September) of 2013 and 2014, the monoculture plantations were 1.25 °C warmer whereas during rainy months they were 1°C warmer than the forest. But during the dry months of 2015, the monoculture plantations were only 1°C warmer than the forest.

The air humidity followed an opposite pattern than air temperature. It was higher in forest and jungle rubber but lower in rubber and oil palm plantations during the entire study period. Except for the dry months of 2015, the weekly mean air humidity was around 90 (vol. %) in rubber and oil palm plantations but it was around 95 (vol. %) in forest and jungle rubber. During the dry months of 2015, the weekly mean air humidity decreased and reached around 85 (vol. %) in all of the land-use systems.

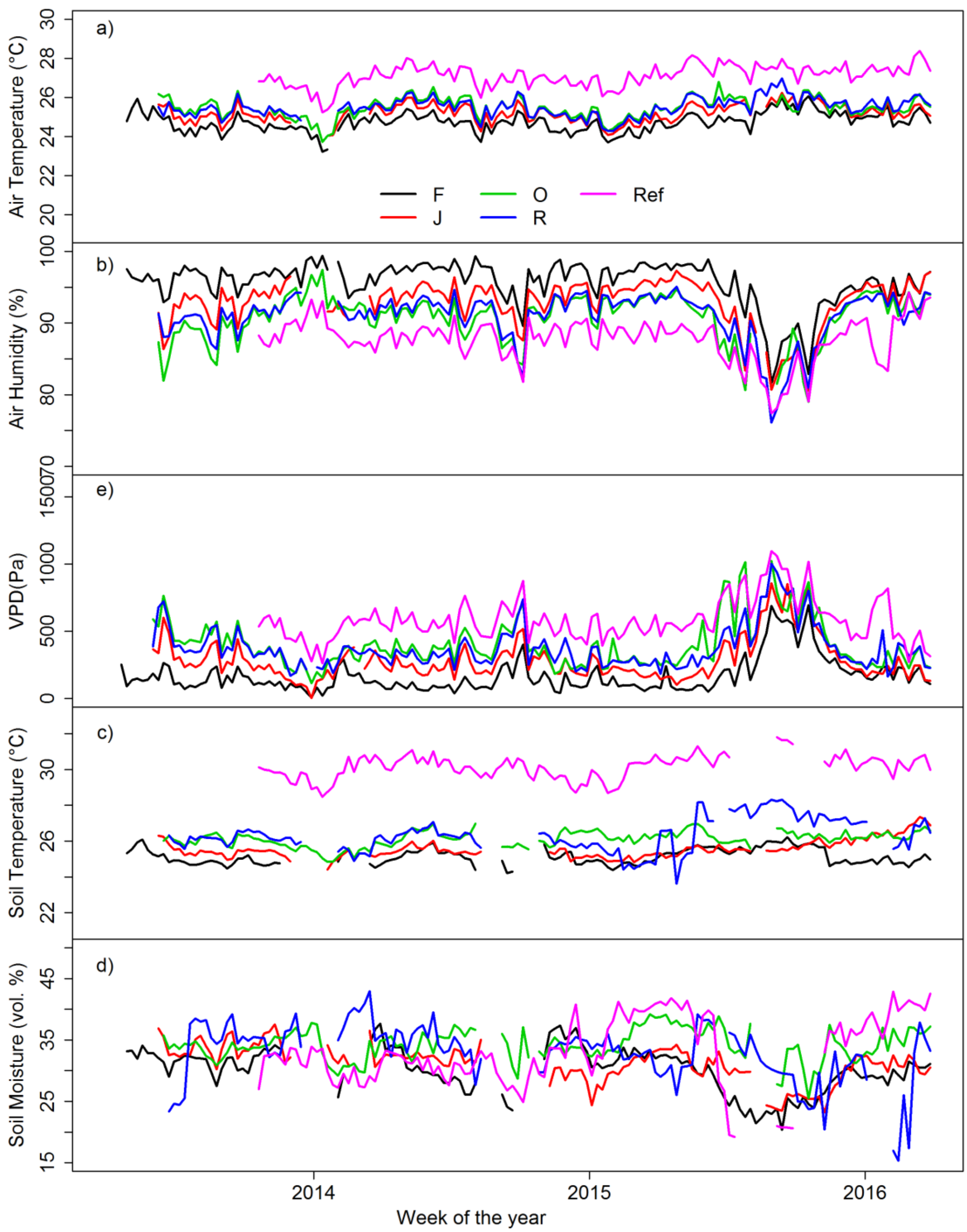


Figure 7: The trends for weekly means of (a) air temperature, (b) relative air humidity, (c) soil moisture, (d) soil temperature and (d) vapour pressure deficit across four land-use systems.

3.3 Diurnal cycles

3.3.1 Mean diurnal cycles for the whole study period across four land-use systems

The mean diurnal cycles of air temperature, air humidity, vapour pressure deficit, soil moisture and soil temperature followed similar trends across four land-use systems (Figure 8). During the night, from 8 pm to 7 am, the mean air temperature (Figure 8a) was similar in all land-use systems. In the morning at 6 am, the air temperature reached its minimum value of around 23 °C in all four land-use systems. After 6 am, with sunrise, air temperature started to increase and reached its maximum value of 30 °C in monoculture plantations but 28 °C in the forest at 2 pm in the afternoon. After 2 pm, air temperature again decreased slowly and reached the same temperature in all four land-use systems at 7 pm in the evening. The mean relative air humidity (Figure 8b) was higher in all land-use systems from 9 pm to 6 am. After 6 am, air humidity decreased and reached its minimum value of 75 (vol. %) in rubber and oil palm plantations and 85 (vol. %) in the forest at 2 pm. After 2 pm, air humidity started to increase slowly in the afternoon and reached the same level for all land-use systems at 9 pm.

Furthermore, the mean vapour pressure deficit (Figure 8c) was minimum at 6 am. It was almost similar in all four land-use systems from 8 pm until 7 am in the morning. Before it begins to decrease after 2 pm, vapour pressure deficit increased and reached its maximum value of 1200 Pa in rubber and oil palm plantations and 600 Pa in the forest at 2 pm. There is not much difference noticed in the diurnal cycle in soil moisture (Figure 8d). In addition to this, the mean soil temperature (Figure 8e) was lowest at 9 am in the morning in all four land-use systems. After 9 am in the morning soil temperature, started to increase.

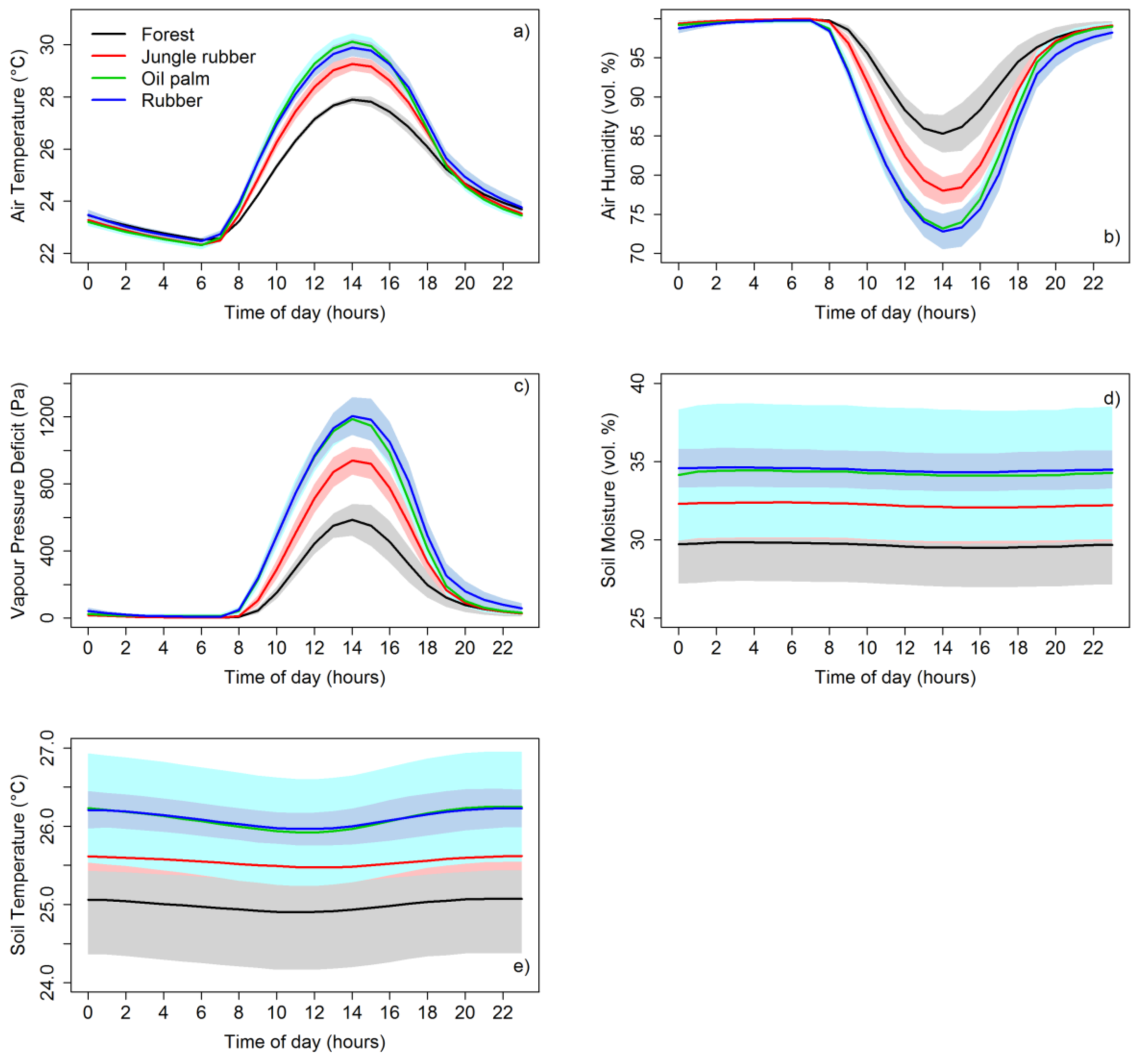


Figure 8: The mean diurnal cycles of a) air temperature, b) relative air humidity, c) vapour pressure deficit, d) soil moisture and e) soil temperature across four different land-use systems.

3.3.2 Diurnal cycles for the whole study period between two landscapes

The mean diurnal cycles of air temperature followed similar trends in both landscapes (Figure 9). Forest and jungle rubber of Bukit and Harapan have similar air temperature throughout day and night. In both regions the mean air temperature was low from 9 pm to 6 am in rubber and oil palm plantations. At 6 am, air temperature touched its minimum value of around 22 °C in both regions of rubber and oil palm plantations. After 6 am air temperature increased and became slightly higher in Bukit region at 3 pm in rubber and oil palm plantations. During the day time, the difference in air temperature was less than 0.5 °C in rubber and oil palm plantations between both regions.

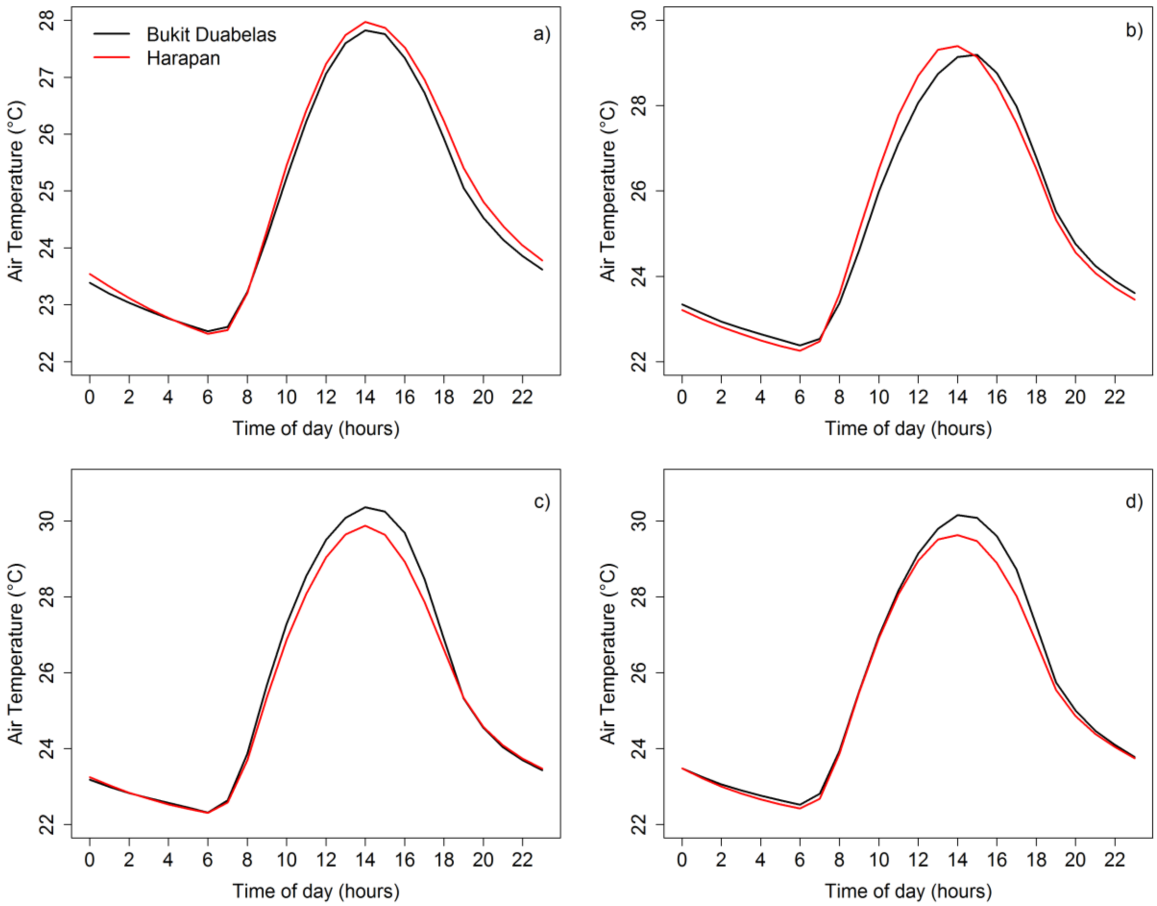


Figure 9: The mean diurnal cycles of air temperature between two different landscapes for a) forest, b) jungle rubber, c) oil palm plantation and d) rubber plantation.

3.3.3 Seasonal variation in diurnal cycles across four land-use systems

During night time, the diurnal cycles of air temperature, relative air humidity and vapour pressure deficit in both wet and dry seasons were similar across all four land-use systems (Figure 10). Rubber and oil palm plantations were hotter during the dry season by a half degree Celsius (Figure 10a). The diurnal cycles of air temperature in jungle rubber remain almost unchanged during both dry and wet season. A negligible drop in day temperature in the forest during the dry season was observed. Further, the vapour pressure deficit was higher in rubber and oil palm plantations at the afternoon of the dry season but lower in forest and jungle rubber than the respective afternoon of the wet season (Figure 10c).

Conversely, at the afternoon of the dry season, air humidity dropped in rubber and oil palm plantations but increased in forest and jungle rubber by less than 4 vol. % (Figure 10b). Accordingly, soil temperature was higher during the dry seasons than during the wet season across four land-use systems (Figure 10d). Moreover, during the dry season, soil moisture was higher in jungle rubber and lower in forest however soil moisture in oil palm and rubber remained unchanged during dry and wet seasons (Figure 10e).

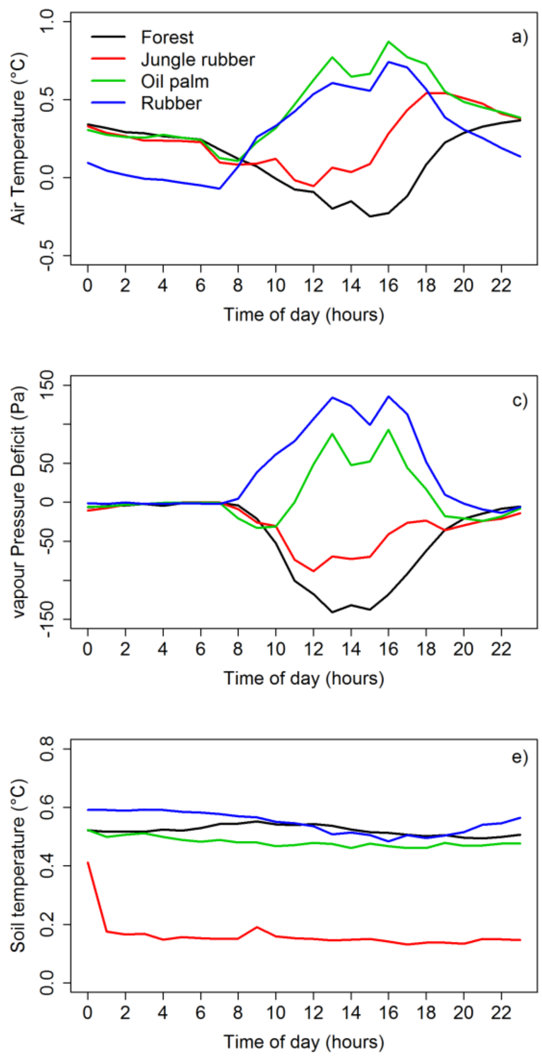


Figure 10: The mean diurnal cycles of the difference between dry season and wet season of a) air temperature, b) relative air humidity, c) vapour pressure deficit, d) soil moisture and e) soil temperature across four land-use systems.

3.4 Means for comparing ENSO

3.4.1 Overall means of measured climate variables during August, September and October of three different years across four land-use systems

The overall means of five different climate variables across four different land-use systems during dry months (August, September and October) of 2013, 2014 and 2015 are given in Table 9 and Figure 11. There was an increase in overall mean air temperature, vapour pressure deficit and soil temperature in 2015 in all of the four land-use systems. There was also decrease in mean relative air humidity and soil moisture in all land-use systems. The mean air temperature in 2015 in forests and jungle rubber increased by about 1 °C, compared to 2013 and 2014. Surprisingly, there was only an increase of about 0.5 °C in rubber and oil palm plantations in 2015. Accordingly, the mean vapour pressure deficit increased more than 300 Pa in forest and jungle rubber and increased around 250 Pa in oil palm and rubber plantations. The mean relative air humidity in forest and jungle rubber dropped by 8 vol. % and it dropped by 5 vol. % in oil palm and rubber plantations.

The mean values of air temperature, air humidity, vapour pressure deficit and soil moisture of 2015 were significantly different with the mean values of 2013 and 2014 across all the four land-use systems (ANOVA F-test, Table 10). There was no significant difference in the mean values of air temperature, air humidity, vapour pressure deficit and soil moisture between 2013 and 2014 (Tukey HSD). The F-statistic and p-value of ANOVA test are given in Table 10. The results from Tukey HSD showing the years with a significant difference with each other of the forest, jungle rubber, oil palm and rubber plantations are shown in Appendix 6, Appendix 7, Appendix 8 and Appendix 9 respectively.

Table 9: Overall mean values (and the margin of error at 95% confidence interval) of the measured climate variables across four different land-use systems during dry months (August, September and October) of 2013, 2014 and 2015.

Land-use (n=8) and year	**Air temperature (°C)**	**Air humidity (vol. %)**	**Soil moisture (vol. %)**	**Soil temperature (°C)**	**Vapour pressure deficit (Pa)**
Forest					
(2013)	24.57 (± 0.16)	95.73 (± 1.14)	30.75 (± 2.32)	24.85 (± 0.44)	155.49 (± 2.33)

Forest (2014)	24.54 (± 0.22)	96.13 (± 1.58)	29.03 (± 3.98)	25.39 (± 0.49)	142.57 (± 8.72)
Forest (2015)	25.52 (± 0.19)	87.37 (± 2.42)	20.58 (± 3.62)	25.64 (± 0.38)	497.22 (± 7.58)
Jungle rubber (2013)	25 (± 0.13)	92.59 (± 1.04)	33.55 (± 3.53)	25.43 (± 0.40)	291.06 (± 3.43)
Jungle rubber (2014)	25.06 (± 0.17)	92.66 (± 1.27)	32.34 (± 2.16)	25.14 (± 0.17)	290.5 (± 50.27)
Jungle rubber (2015)	25.98 (± 0.21)	84.17 (± 2.08)	26.34 (± 5.20)	25.71 (± 0.36)	589.35 (± 60.55)
Oil palm (2013)	25.46 (± 0.06)	89.34 (± 0.69)	33.94 (± 1.49)	26.14 (± 0.31)	433.62 (± 6.31)
Oil palm (2014)	25.47 (± 0.18)	89.42 (± 1.39)	35.13 (± 1.85)	25.49 (± 0.97)	425.05 (± 4.24)
Oil palm (2015)	26.08 (± 0.30)	82.6 (± 1.94)	30.20 (± 6.50)	26.27 (± 0.25)	689.05 (± 3.44)
Rubber (2013)	25.38 (± 0.22)	89.75 (± 1.46)	34.66 (± 5.17)	26.02 (± 0.34)	413.35 (± 9.68)
Rubber (2014)	25.31 (± 0.23)	91.02 (± 0.99)	32.89 (± 5.37)	26.17 (± 0.59)	359.69 (± 6.06)
Rubber (2015)	26.01 (± 0.12)	84.23 (± 1.21)	25.41 (± 5.17)	27.10 (± 0.51)	658.55 (± 9.43)

Table 10: F-statistic and p-values of ANOVA test for testing differences in mean values of three different years across four land-use systems.

Effect	**Climate variable**	**F - statistic**	**p-value**
ENSO (Forest)	Air temperature	32.54	< 0.001
ENSO (Jungle rubber)		35.77	< 0.001
ENSO (Oil palm)		11.05	< 0.001
ENSO (Rubber)		11.35	< 0.001
ENSO (Forest)	Air Humidity	29.23	< 0.001
ENSO (Jungle rubber)		37.24	< 0.001

ENSO (Oil palm)		25.46	< 0.001
ENSO (Rubber)		28.64	< 0.001
ENSO (Forest)	VPD	36.11	< 0.001
ENSO (Jungle rubber)		11.34	< 0.001
ENSO (Oil palm)		30.79	< 0.001
ENSO (Rubber)		28.72	< 0.001
ENSO (Forest)	Soil temperature	2.87	0.083
ENSO (Jungle rubber)		1.86	0.188
ENSO (Oil palm)		3.57	0.054
ENSO (Rubber)		1.74	0.202
ENSO (Forest)	Soil Moisture	8.70	< 0.001
ENSO (Jungle rubber)		3.05	0.076
ENSO (Oil palm)		2.06	0.162
ENSO (Rubber)		1.39	0.274

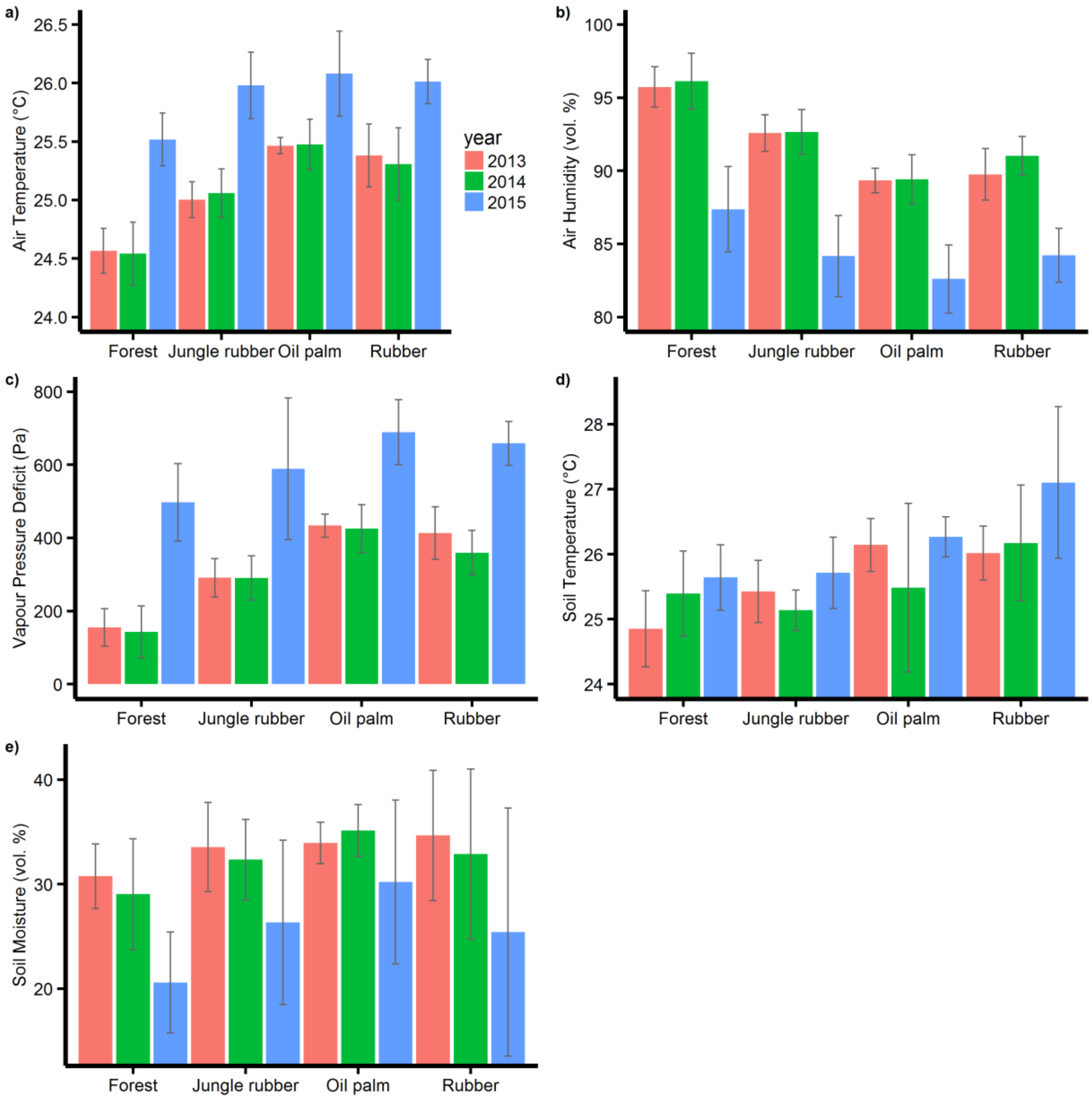


Figure 11: The overall means of the daily values of five different climate variables across four land-use systems during dry ENSO months (August, September and October) of 2013, 2014 and 2015 of a) air temperature, b) air humidity, c) vapour pressure deficit, d) soil temperature and e) soil moisture. Lines over bars represents the margin of error at 95% confidence interval.

The overall mean daily maximum air temperature, vapour pressure deficit and soil temperature were even higher in 2015 than they were in 2013 and 2014. The minimum relative humidity in 2015 dropped by more than 20 vol. % in the forest whereas it dropped by less than 15 vol. % in oil palm and rubber plantations. The overall mean daily maximum and minimum values of the five climatic variables across four land-use systems during dry months (August, September and October) of 2013, 2014 and 2015 are given in Table 11 and Table 12.

Table 11: Overall mean values of the daily maximum (and the margin of error at 95% confidence interval) of measured climate variables across four different land-use systems during dry months (August, September and October) of 2013, 2014 and 2015.

Land-use (n=8) and year	Air temperature (°C)	Air humidity (vol. %)	Soil moisture (vol. %)	Soil temperature (°C)	Vapour pressure deficit (Pa)
Forest (2013)	27.94 (± 0.22)	99.99 (± 0.01)	31.58 (± 2.45)	25.01 (± 0.43)	696.94 (± 103.44)
Forest (2014)	27.89 (± 0.47)	99.99 (± 0.02)	30.15 (± 4.34)	25.58 (± 0.51)	636.96 (± 191.42)
Forest (2015)	30.23 (± 0.45)	99.41 (± 0.55)	21.0 (± 3.54)	25.8 (± 0.37)	1575.94 (± 169.80)
Jungle rubber (2013)	29.72 (± 0.43)	100 (± 0)	34.65 (± 3.75)	25.57 (± 0.40)	1178.99 (± 121.62)
Jungle rubber (2014)	29.83 (± 0.42)	99.99 (± 0.01)	33.02 (± 2.18)	25.27 (± 0.16)	1174.58 (± 120.04)
Jungle rubber (2015)	31.8 (± 0.35)	99.35 (± 0.41)	26.78 (± 5.26)	25.93 (± 0.34)	1751.28 (± 487.33)
Oil palm (2013)	30.69 (± 0.16)	99.98 (± 0.02)	34.69 (± 1.50)	26.35 (± 0.32)	1508.22 (± 41.77)
Oil palm (2014)	30.73 (± 0.17)	99.95 (± 0.07)	36 (± 1.93)	25.76 (± 0.91)	1509.69 (± 113.91)
Oil palm (2015)	31.73 (± 0.44)	99.13 (± 0.56)	30.54 (± 6.63)	26.49 (± 0.28)	1967.1 (± 151.18)
Rubber (2013)	30.88 (± 0.39)	99.9 (± 0.16)	35.71 (± 5)	26.24 (± 0.34)	1505.29 (± 127.36)
Rubber (2014)	30.83 (± 0.45)	100 (± 0)	34.06 (± 5.49)	26.48 (± 0.57)	1372.6 (± 117.40)
Rubber (2015)	31.91 (± 0.25)	99.64 (± 0.31)	25.6 (± 5.22)	27.48 (± 0.58)	2010.6 (± 80.23)

Table 12: Overall mean values of the daily minimum (and the margin of error at 95% confidence interval) of measured climate variables across four different land-use systems during dry months (August, September and October) of 2013, 2014 and 2015.

Land-use (n=8) and year	Air temperature (°C)	Air humidity (vol. %)	Soil moisture (vol. %)	Soil temperature (°C)	Vapour pressure deficit (Pa)
Forest (2013)	22.13 (± 0.10)	81.71 (± 2.54)	30.17 (± 2.29)	24.7 (± 0.44)	0.58 (± 0.95)
Forest (2014)	22.16 (± 0.11)	83.06 (± 4.83)	28.37 (± 3.87)	25.19 (± 0.48)	0.45 (± 0.73)
Forest (2015)	22.13 (± 0.15)	64.03 (± 3.26)	20.11 (± 3.72)	25.48 (± 0.39)	17.75 (± 15.96)
Jungle rubber (2013)	21.85 (± 0.06)	72.12 (± 2.30)	32.88 (± 3.49)	25.3 (± 0.40)	0.05 (± 0.09)
Jungle rubber (2014)	21.94 (± 0.15)	72.33 (± 2.45)	31.64 (± 2.14)	24.98 (± 0.19)	0.48 (± 0.93)
Jungle rubber (2015)	21.88 ± 0.27)	57.63 (± 2.58)	25.99(± 5.12)	25.52 (± 0.37)	36.17 (± 25.75)
Oil palm (2013)	21.93 (± 0.07)	65.76 (± 0.77)	33.46 (± 1.45)	25.96 (± 0.29)	11.18 (± 20.80)
Oil palm (2014)	22.01 (± 0.19)	65.67 (± 2.26)	34.51 (± 1.78)	25.26 (± 0.98)	2.96 (± 3.70)
Oil palm (2015)	22.02 (± 0.27)	56 (± 2.44)	29.82 (± 6.37)	26.04 (± 0.24)	41.98 (± 23.88)
Rubber (2013)	21.83 (± 0.14)	66.42 (± 2.11)	33.89 (± 5.13)	25.82 (± 0.35)	2.86 (± 4.41)
Rubber (2014)	21.81 (± 0.13)	68.23 (± 2.03)	32.22 (± 5.23)	25.9 (± 0.60)	4.09 (± 4.94)
Rubber (2015)	21.86 (± 0.05)	57.59 (± 1.11)	25.2 (± 5.10)	26.74 (± 0.46)	16.16 (± 8.70)

3.4.2 Mean diurnal cycles before and after ENSO events between four land-use systems

The mean diurnal cycles of all the five measured climate variables during August, September and October of 2013, 2014 and 2015 followed identical trends across four land-use systems. All of the measured climate variables have similar diurnal cycles in 2013 and 2014 in all four land-use systems. During the day time of 2015, the diurnal cycle of air temperature increased in all land-use systems.

After 6 am, the air temperature started to increase in all three years and reached its maximum value during daytime at 2 pm in all land-use systems (Figure 12). In 2015, a higher increase in mean air temperature of the forest was found, compared to other land-use systems (Figure 12a). In 2015, the mean air temperature in forest reached around 30 °C at 2 pm, while it was only around 27 °C in 2013 and 2014. After forest, the effect of ENSO was more pronounced in jungle rubber (Figure 12b). It experienced an increase of 2 °C in 2015 as compared to 2013 and 2014. Rubber and oil palm plantations were the least affected land-use systems with an increase of less than 1 °C in mean air temperature (Figure 12c and Figure 12d).

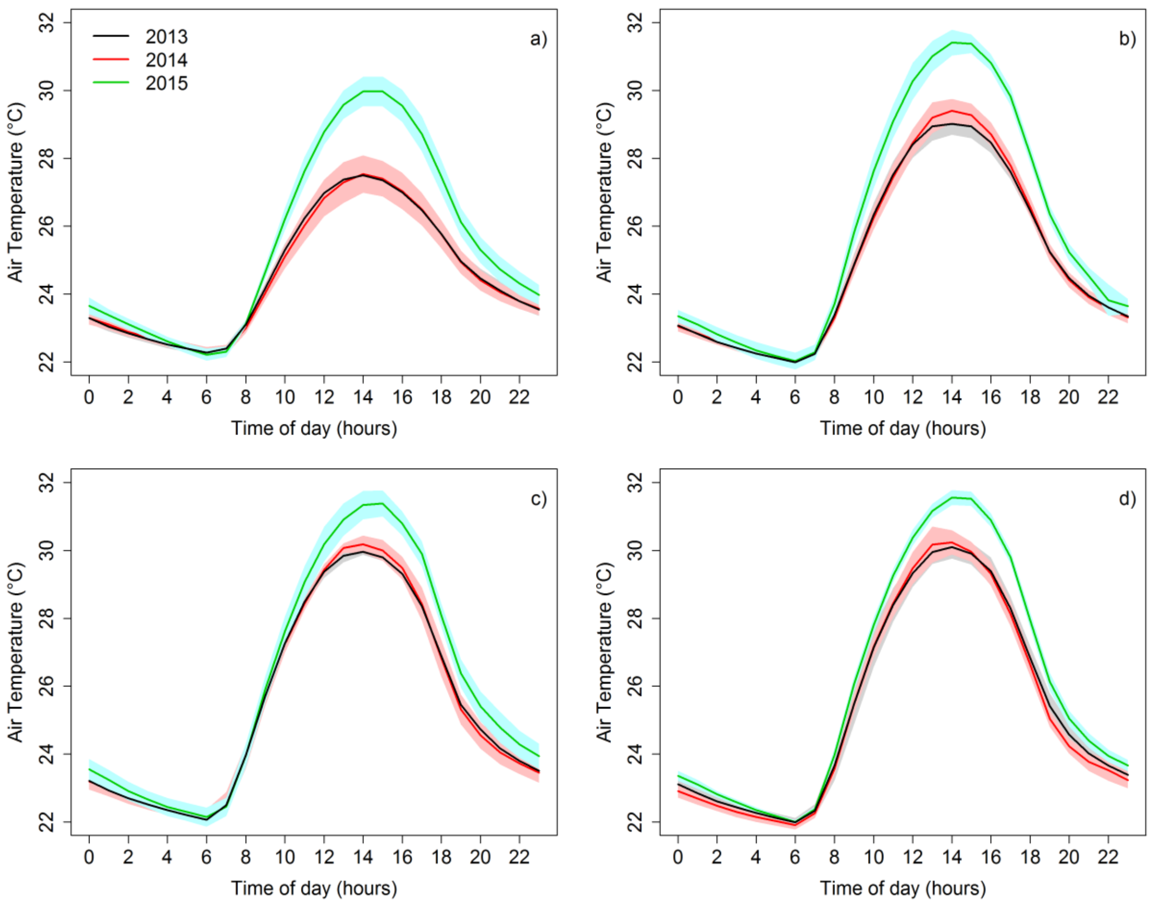


Figure 12: The mean diurnal cycles of mean air temperature of a) forest, b) jungle rubber, c) rubber plantation and d) oil palm plantation during dry months (August, September and October) of 2013, 2014 and 2015.

After 6 am, relative air humidity decreased in all land-use systems in three years. The air humidity reached its minimum value at 2 pm (Figure 13). In 2015, mean air humidity in forest reached around 65 (vol. %) at 2 pm, while it was only around 85 (vol. %) in 2013 and 2014 (Figure 13a). After forest, the effect of ENSO was more pronounced in jungle rubber (Figure 13b). Similarly, the air humidity of jungle rubber decreased by 20 (vol. %) in 2015 compared to 2013 and 2014. Rubber and oil palm plantations were the least affected land-use systems with decreases of less than 10 (vol. %) in mean air humidity (Figure 13c and Figure 13d).

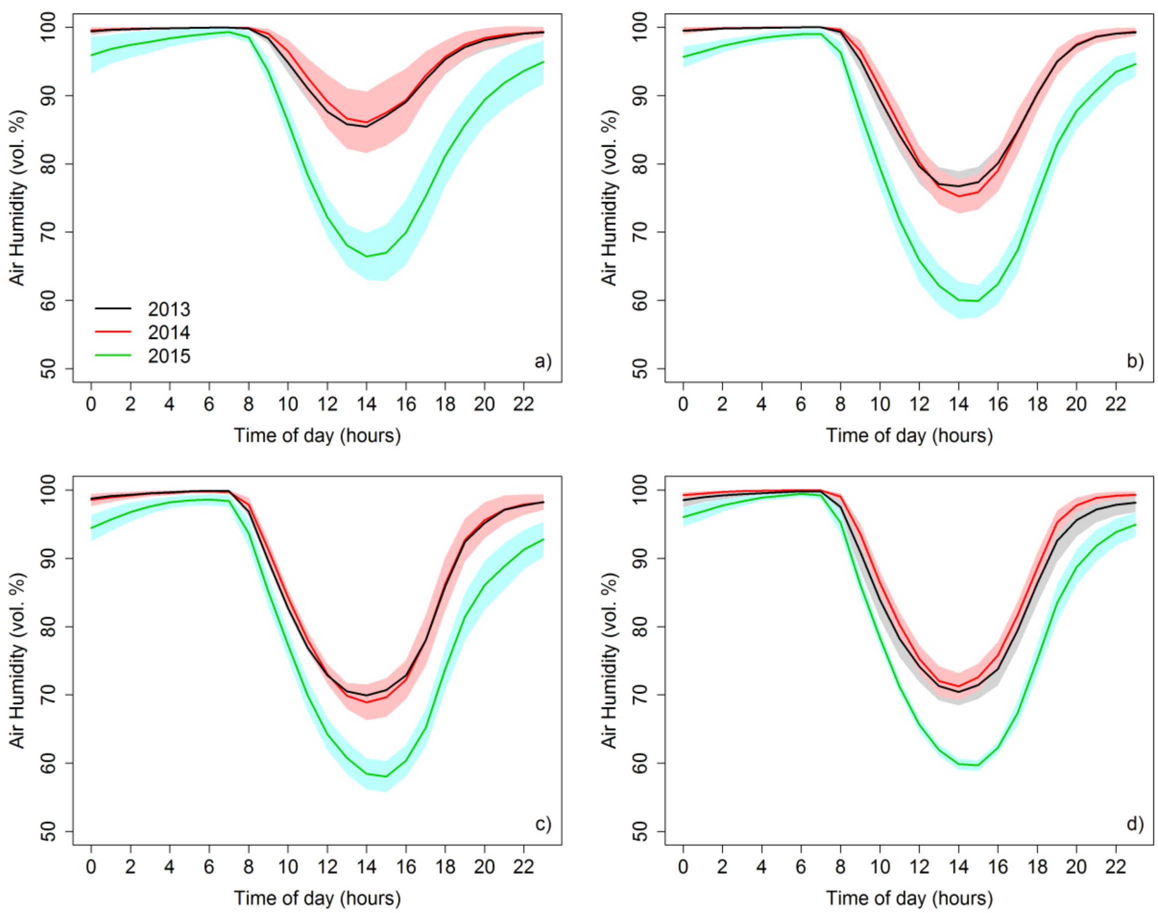


Figure 13: The mean diurnal cycles of mean air humidity of a) forest, b) jungle rubber, c) rubber plantation and d) oil palm plantation during dry months (August, September and October) of 2013, 2014 and 2015.

After 6 am, vapour pressure deficit increased in three years and reached its maximum value at 2 pm (Figure 14). Although there was an increase in vapour pressure deficit at all of the land-use systems in 2015, forest experienced the highest increase. In 2015, the mean vapour pressure deficit of forest was 1500 Pa at 2 pm, while it was only around 500 Pa in 2013 and 2014 (Figure 14a). Similarly, in jungle rubber vapour pressure deficit reached around 1700 Pa in 2015 while it was less than 1000 Pa in 2013 and 2014 (Figure 14b). Rubber and oil palm plantations were the least affected land-use systems with increases of less than 500 Pa (Figure 14c and Figure 14d).

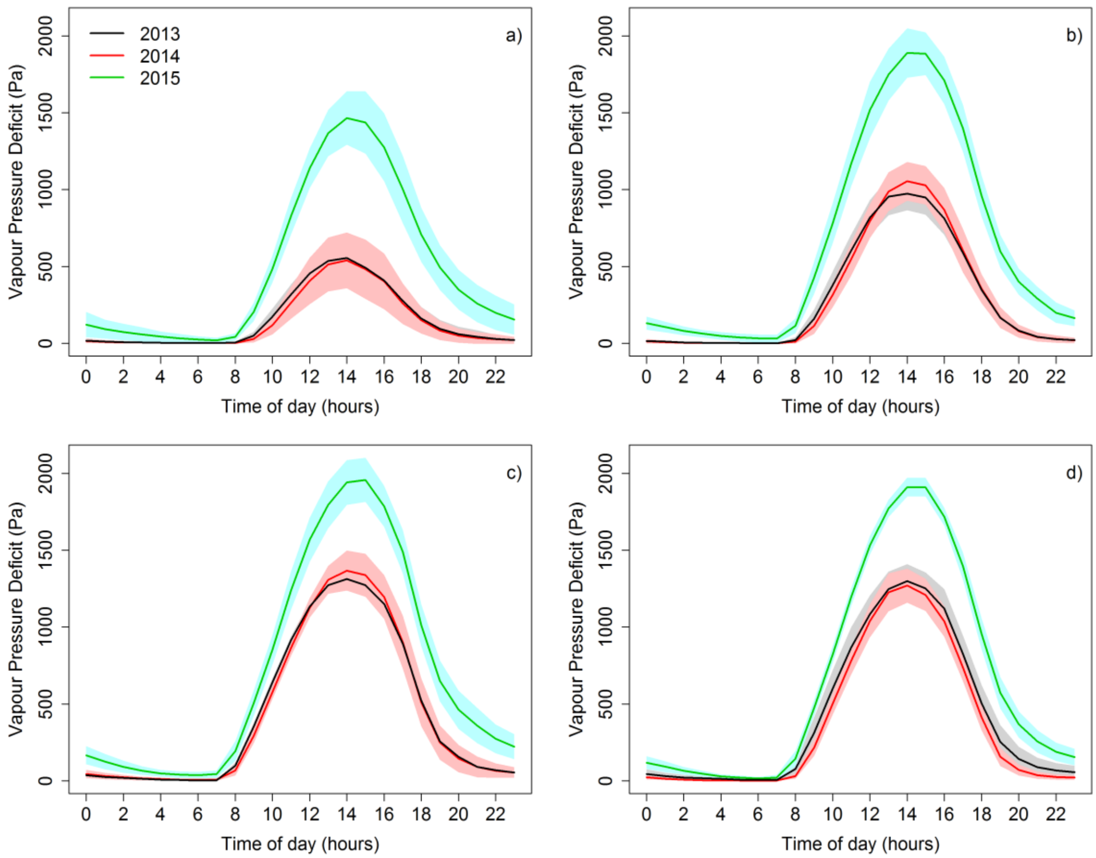


Figure 14: The mean diurnal cycles of mean vapour pressure deficit of a) forest, b) jungle rubber, c) rubber plantation and d) oil palm plantation during dry months (August, September and October) of 2013, 2014 and 2015.

3.5 Relationship between canopy openness and measured climatic variables

3.5.1 Means of canopy openness of four land-use systems

The canopy openness of forest was lowest with 2.54 %. Oil palm plantation had the highest canopy openness with 15.64 %. The mean canopy openness values of the four land-use systems are given in Table 13.

Table 13: Mean canopy openness (and the margin of error at 95% confidence interval) of four land-use systems.

Land-use (n=8)	**Canopy openness (%)**
Forest	2.54 (± 0.33)
Jungle rubber	7.10 (± 1.42)
Oil palm	15.64 (± 2.94)

Rubber	13.46 (± 2.38)

3.5.2 Canopy openness and measured climatic variables

There was a non-linear logarithmic relationship between the mean canopy openness and the mean of the measured climate variables. The best fitted model for canopy openness and climate variables is given in equation 4.

$$y = 3 \times \log(x) \tag{4}$$

where, y = climate variables (air temperature, air humidity, vapour pressure deficit, soil temperature and soil moisture) and x = canopy openness.

The daily mean air temperature (Figure 15a; $R^2 = 0.75$, $F_{1, 29} = 84.85$, $p < 0.001$) and vapour pressure deficit (Figure 15c; $R^2 = 0.71$, $F_{1, 29} = 69.49$, $p < 0.001$) had strong positive relationship with mean canopy openness. Similarly, the daily mean soil temperature (Figure 15d; $R^2 = 0.24$, $F_{1, 29} = 9.40$, $p < 0.001$) and soil moisture (Figure 15e; $R^2 = 0.15$, $F_{1, 29} = 5.03$, $p = 0.033$) also had positive relationship with canopy openness. But daily mean relative air humidity (Figure 15b; $R^2 = 0.68$, $F_{1, 29} = 61.5$, $p < 0.001$) had strong negative relationship with canopy openness.

Moreover, the mean daily maximum air temperature (Figure 16a; $R^2 = 0.82$, $F_{1, 29} = 131$, $p < 0.001$) and vapour pressure deficit (Figure 16c; $R^2 = 0.78$, $F_{1, 29} = 102.9$, $p < 0.001$) had strong positive relationship with canopy openness, whereas mean daily minimum relative humidity (Figure 16b; $R^2 = 0.75$, $F_{1, 29} = 89.22$, $p < 0.001$) had strong negative relationship with canopy openness. The mean daily minimum air temperature (Figure 16a; $R^2 = 0.11$, $F_{1, 29} = 3.76$, $p = 0.062$) and mean daily maximum air humidity (Figure 16b; $R^2 = 0.02$, $F_{1, 29} = 0.448$, $p = 0.509$) also had small but significant relationship with canopy openness.

Further, the daily standard deviations of maximum air temperature (Figure 17a; $R^2 < 0.13$, $F_{1, 29} = 4.41$, $p = 0.045$), maximum vapor pressure deficit (Figure 17c; $R^2 = 0.04$, $F_{1, 29} = 3.22$, $p = 0.268$), minimum vapour pressure deficit (Figure 17c; $R^2 = 0.1$, $F_{1, 29} = 3.22$, $p = 0.083$), and minimum air temperature (Figure 17a; $R^2 = 0.16$, $F_{1, 29} = 5.40$, $p = 0.027$) were positively related to canopy openness. The daily standard deviations of minimum air humidity (Figure 17b; $R^2 = 0.35$, $F_{1, 29} = 15.49$, $p < 0.001$) was negatively related to canopy openness. There was also significant relationship between standard deviations of maximum air humidity

(Figure 17b; R^2 =0.03, $F_{1, 29}$ = 0.97, p = 0.332) and standard deviations of minimum soil moisture (Figure 17d; R^2 =0.03, $F_{1, 29}$ = 0.85, p = 0.365).

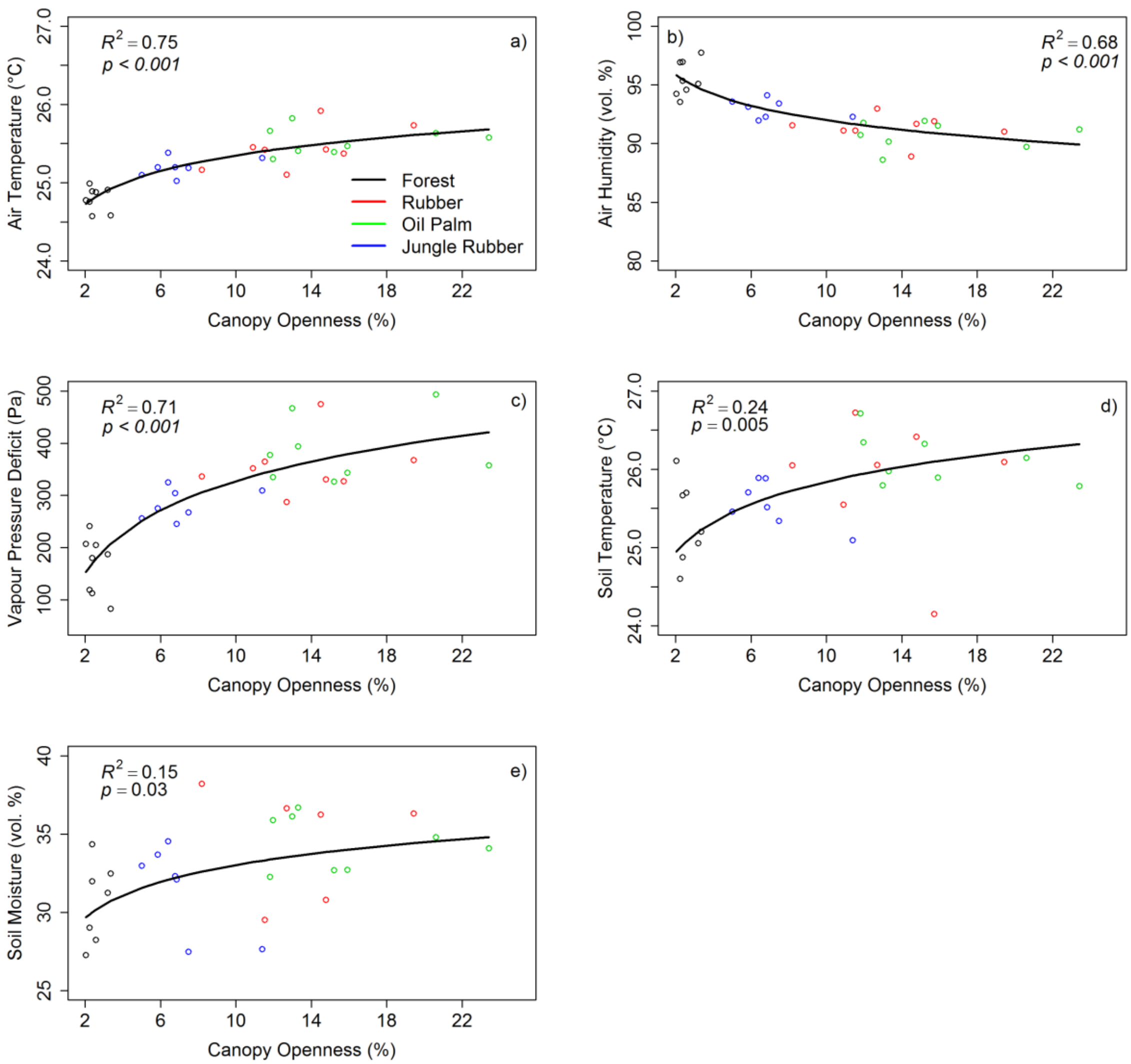


Figure 15: The relationship between canopy openness and mean a) air temperature, b) air humidity, c) vapour pressure deficit, d) soil temperature and e) soil moisture.

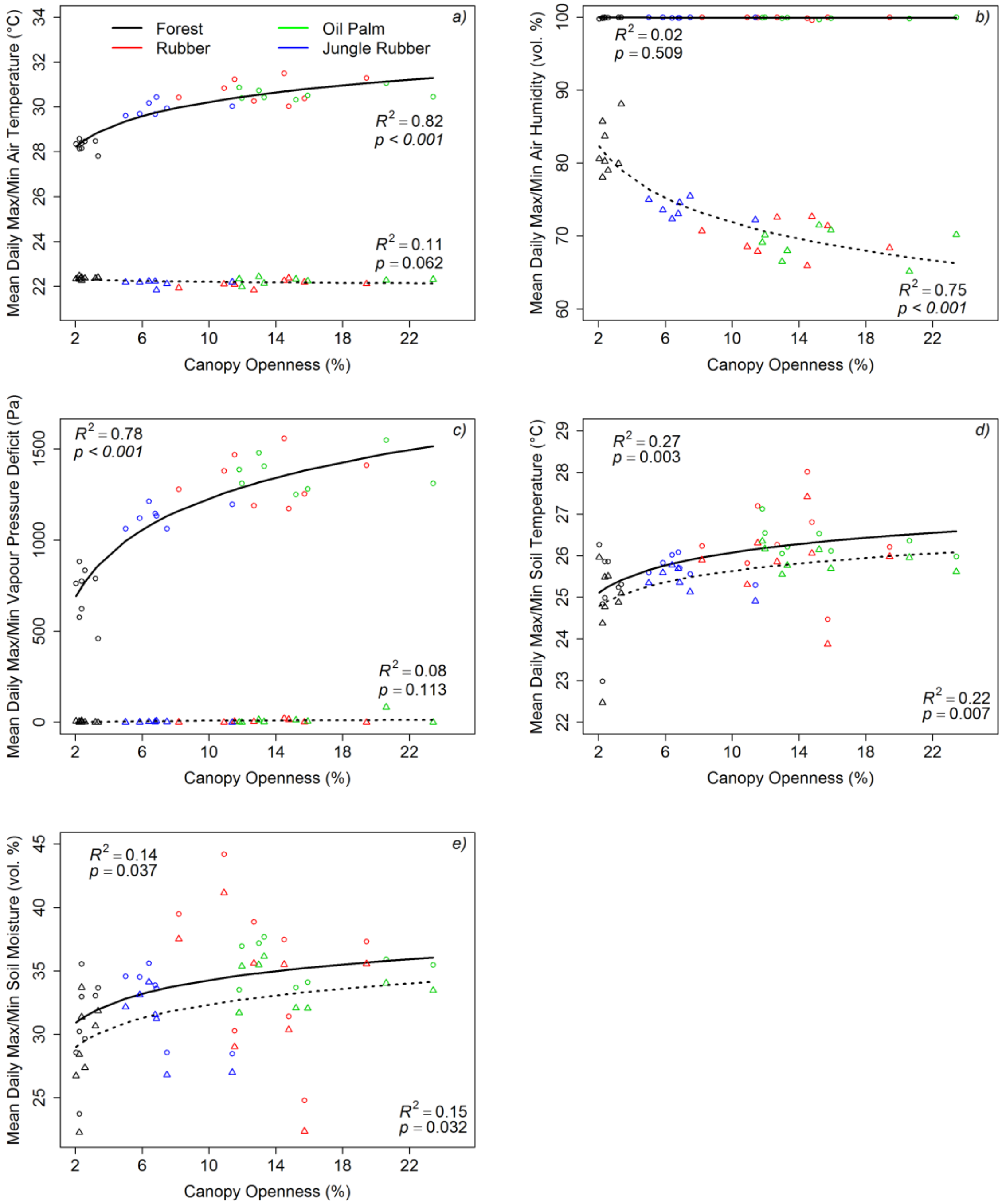


Figure 16: The relationship between canopy openness and mean daily max/min (a) air temperature, (b) air humidity, (c) vapour pressure deficit, (d) soil temperature and (e) soil moisture. Dashed lines indicate mean daily minimum.

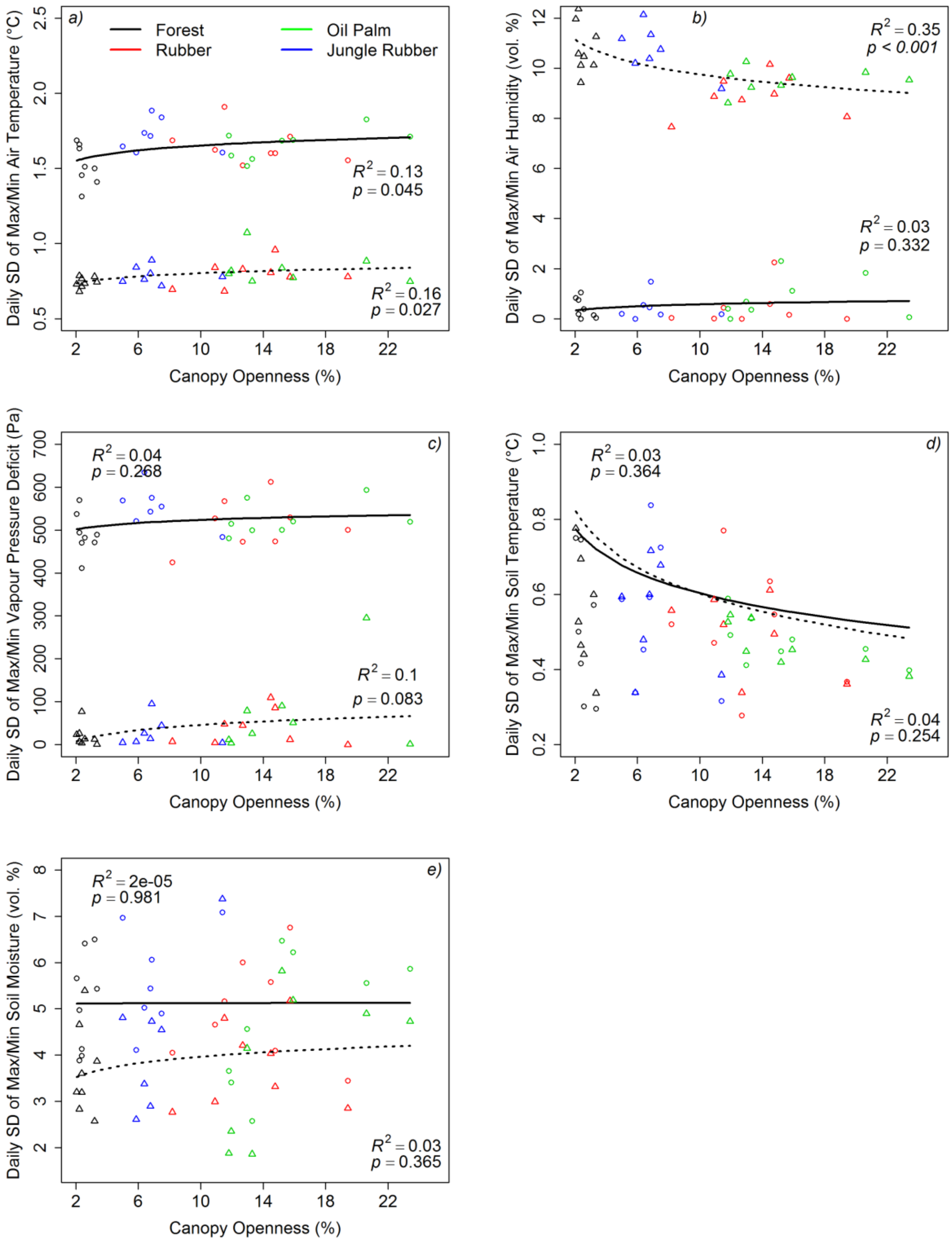


Figure 17: The relationship between canopy openness and standard deviations of the maximum and minimum (a) air temperature, (b) air humidity, (c) vapour pressure deficit, (d) soil temperature and (e) soil moisture. Dashed lines indicate the standard deviation of the mean daily minimum.

4. Discussions

Our results indicate that the conversion of forest to jungle rubber, rubber and oil palm plantations in Jambi modifies the microclimatic components such as air temperature, air humidity, vapour pressure deficit, soil temperature and soil moisture, which is consistent with our hypotheses. Also, the strong ENSO event of 2015 increased the air and soil temperature but decreased air humidity and soil moisture.

4.1 Microclimate and land-use change

Forest and jungle rubber were less warm and drier than rubber and oil palm plantations. The mean air temperature, relative air humidity and vapour pressure deficit were similar for oil palm and rubber plantations. Also, the mean daily maximum and minimum air temperature, relative air humidity and vapour pressure deficit were almost similar for oil palm and rubber plantations. Moreover, the canopy openness of rubber and oil palm plantations were also very close to each other.

Furthermore, we found no significant difference in the overall means of air temperature, relative air humidity and vapour pressure deficit of rubber and oil palm plantations. However, we observed the significant difference between the means of air temperature, relative air humidity and vapour pressure deficit of other land-use systems. Our results from overall means, weekly means and diurnal cycles also revealed that monoculture plantations were warmer and drier than forest and jungle rubber. During the dry months of 2015, from August to October, the weekly air temperature started to increase while air humidity started to decrease in all land-use systems. But surprisingly during that period, weekly air temperature started to increase earlier than air humidity started to decrease. This might be because of the effect of ENSO 2015 in that region.

Our results are in agreement with various studies that found an increase in air temperature and a decrease of relative air humidity caused by the conversion of forest to other land-use systems. Hardwick et al. (2015) and Luskin & Potts (2011) claimed that conversion of forest to oil palm plantations has resulted in warmer and drier conditions. Marshall et al. (2004) also reported that conversion of forest to agricultural lands has led to an increase in air temperature and a decrease in relative air humidity. Further, Peng et al. (2014), Baidya Roy et al. (2003) and Jackson et al. (2008) also stated that afforestation and reforestation programmes have led to decrease in air temperature.

4.2 Effects of canopy openness on microclimate

Studies by (Beltrán-Przekurat et al. 2008; Betts 2001) suggested that the modification of microclimate can be linked to the vegetation cover and seasonality. Our seasonal diurnal cycles demonstrate that monoculture plantations still remain hotter and drier than the forest in both seasons (i.e. dry and wet). Even during the extreme ENSO event of 2015 monoculture plantations remain hotter and drier than the forest and jungle rubber. So higher air temperature and relative air humidity in monoculture plantations can be linked to the increase in canopy openness. Hardwick et al. (2015) also indicated that leaf area index is negatively correlated to air temperature whereas positively related to relative air humidity. This is because tree canopies limit the amount of sunlight reaching the soil surface and thus reduce the air and soil temperature under the forest canopy (Bhatti et al. 2016). This explains why in our results the soil temperature in rubber and oil palm plantations is higher and lower in forest and jungle rubber. We also identified a strong positive relationship between canopy openness and air temperature and vapour pressure deficit but a strong negative relationship between canopy openness and relative air humidity which were compatible with our hypothesis that with increasing canopy openness, air temperature and soil temperature increase, while air humidity and soil moisture decrease.

Furthermore, during the day time when sunlight is incident on the plant canopy, most of it is absorbed by the leaves, twigs and branches while the remaining is reflected. The sunlight which is absorbed by the leaves will heat up the leaves and the air below the canopy. Solar radiation which is not absorbed or reflected by the plant canopy enters the soil and heat the soil surface. The heat from the soil surface is then transferred back into the air below the canopy. Therefore, the air temperature below the canopy strongly depends on the amount of heat absorbed by the plant canopy and soil surface. The land-use system with more canopy opening will allow more heat to reach the soil surface and thus will have higher air temperature, than a land-use system with lower canopy opening, which corresponds to a lower air temperature. In the same way, the higher temperature during the day time results in an increase in saturated water vapour pressure which in turn increases vapour pressure deficit.

Because of this, the areas with higher percentage of canopy opening and air temperature will have high vapour pressure deficit and low relative air humidity.

In our case, forest and jungle rubber have a small percentage of canopy opening but rubber and oil palm plantations have a higher percentage of canopy opening. Forest and jungle rubber with high canopy coverage have only a small proportion of heat below the canopy. As a result of this, they have low vapour pressure deficit, air and soil temperature but a high percentage of relative air humidity. On the other hand, rubber and oil palm plantations with less canopy coverage store a high proportion of heat below the canopy. For this reason, vapour pressure deficit, air and soil temperature are higher whereas the relative air humidity is lower in rubber and oil palm plantations.

We observed no landscape effect on air temperature, air humidity, vapour pressure deficit and soil temperature. In a sharp contrast, we noticed significant mean differences of soil moisture between the two different landscapes. This might be because of the difference in soil texture. Since the soil of the Bukit region consists of a clay soil, which is known to have higher soil moisture contents. This result is consistent with the study made by Yang et al. (2016) where they found that soil moisture increases with increase in clay and silt content. Similarly, Williams et al. (1983) also reported that soil moisture depends on texture, structure and clay.

4.3 Effects of ENSO

The effect of the strong ENSO event of 2015 was pronounced in all of the four land-use systems. There was an increase in air temperature, soil temperature and vapour pressure deficit but a decrease in air humidity and soil moisture in all of the land-use systems. This might be because of the reduced evapotranspiration during the ENSO period. Due to the drought caused by the ENSO, there was less water available for transpiration from plants and for evaporation from the soil. Reduced evapotranspiration means a decrease in atmospheric and surface cooling. Therefore the air inside the canopy remained hotter and drier during the ENSO period than the normal period in all land-use systems.

Surprisingly, there was a greater increase of the air temperature, soil temperature and vapour pressure deficit and a greater decrease in relative air humidity and soil moisture in forest and jungle rubber than in oil palm and rubber plantations. This increase of air temperature and a decrease of air humidity in forest and jungle rubber are inconsistent with our hypothesis that the effect of ENSO induced drought and high temperatures on microclimate are less pronounced in primary forests than in rubber and oil palm plantations. This can be explained in terms of the decrease in the buffering capacity of the forest. During the ENSO events, the variation of air temperature outside the canopy is much higher than the usual condition. This increased variation in air temperature may lead to the decrease in the buffering capacity of the forest than the normal condition (Frey et al. 2016). As the air temperature outside canopy increases above a certain threshold, the forest cannot keep on buffering which will result in an increase of air temperature than normal condition. On the other hand due to less buffering effect in rubber and oil palm plantations the air temperature inside the canopy during the day time is already very close to the air temperature outside the canopy. This might likely be the reason why we observed a higher increase of air temperature in forest and jungle rubber than in oil palm and rubber plantations.

4.4 Biodiversity and microclimate

The observed differences in microclimatic conditions resulting from the conversion of forest to monoculture plantations might disturb the natural habitat of the floral and faunal species which are dependent on the forest. Foster et al. 2011 identified that the hot and dry conditions produced by the forest conversion to monoculture plantations led to the decline of the biodiversity in Southeast Asia. The unfavorable conditions will ultimately affect the environment of those species which are adapted to moist forest. The decrease in the habitat of certain species due to the conversion of the forest to other land-use systems will cause the reduction in population size of that particular species. This may lead to the extinction of the species and loss of biodiversity. Mostly amphibians, reptiles and the understory vegetation which require moist conditions to survive will be most affected by the observed change in the microclimatic conditions (Chaudhary & Kastner 2016).

Moreover, the observed modification of microclimate produced by the conversion of forest to rubber and oil palm plantations may disturb the soil carbon dynamics. Guo & Gifford (2002) reported that conversion of the primary forest to plantation area and crop land has led to the decrease in the soil carbon stocks by 13% and 42% respectively. They also stated that replacement of cropland to the plantation and secondary forest resulted in an increased percentage of soil carbon stocks by 18% and 53% respectively.

5. Conclusion

This study showed that conversion of forest to monoculture plantations has led to increase in mean air temperature, soil temperature and vapour pressure deficit whereas a decrease in relative air humidity. Accordingly, there was no relationship between soil moisture and land-use systems rather we found a relationship between soil moisture and landscapes that could be attributed to the difference in soil texture. ENSO event of 2015 led to an increase of the mean air temperature, soil temperature and vapour pressure deficit but a decrease of the relative air humidity and soil moisture in all of the land-use systems. Furthermore, we found a larger increase of the air temperature and vapour pressure deficit as well as a decrease of relative air humidity in forest and jungle rubber in 2015. Moreover, this study also revealed that canopy openness has a positive relationship with air temperature, soil temperature and vapour pressure deficit but negative relationship with air humidity.

Thus we can summarize that rubber and oil palm plantations were hotter and drier than forest and jungle rubber. Based on the results, it can be concluded that all the land-use systems including forest, jungle rubber, and oil palm and rubber plantations were affected by ENSO event 2015. Additionally, the effect of ENSO event was more pronounced in forest and jungle rubber than in oil palm and rubber plantations. Under those circumstances, considering microclimate of an area, agroforestry systems with rubber and oil palm plantations can be a suitable option that can maintain the microclimate of an area and fulfill the growing demand for oil palm and rubber.

6. Bibliography

Adams, J., 2010a. *Forests, in the vegetation-climate interaction. How plants make the global environment* 2nd ed., Praxis publishing ltd, Chichester, UK.

Adams, J., 2010b. *Microclimates and vegetation, in the vegetation-climate interaction. How plants make the global environment* 2nd ed., Praxis publishing ltd, Chichester, UK.

Alkama, R. & Cescatti, A., 2016. Biophysical climate impacts of recent changes in global forest cover. *Science*, 351(6273), pp.600–604.

Baidya Roy, S. et al., 2003. Impact of historical land cover change on the July climate of the United States. *Journal of Geophysical Research*, 108, pp.1–14.

Beltrán-Przekurat, A. et al., 2008. Modeling the effects of historical vegetation change on near-surface atmosphere in the northern Chihuahuan Desert. *Journal of Arid Environments*, 72(10), pp.1897–1910.

Betts, A.K. & Ball, J.H., 1997. Albedo over the boreal forest. *Journal of Geophysical Research*, 102(D24), pp.28901–28909.

Betts, R.A., 2001. Biogeophysical impacts of land use on present-day climate: near-surface temperature change and radiative forcing. *Atmospheric Science Letters*, 2, pp.39–51.

Bhatti, V., Gupta, A. & Gupta, N., 2016. Vegetation and Microclimate (Case Study of Shri Mata Vaishno Devi University , Katra J & K). *International Journal of Scientific Research*, 5, pp.1–3.

Bolton, D., 1980. The Computation of Equivalent Potential Temperature. *Monthly Weather Review*, 108, pp.1046–1053.

Brack, D., 2014. *Sustainable Development Goals and forests*, Available at: www.iied.org/pubs.

Chappell, N.A., Bidin, K. & Tych, W., 2001. Modelling rainfall and canopy controls on net-precipitation beneath selectively-logged tropical forest. *Plant Ecology*, 153(1), pp.215–229.

Chaudhary, A. & Kastner, T., 2016. Land use biodiversity impacts embodied in international food trade. *Global Environmental Change*, 38, pp.195–204.

Chen, J. et al., 1999. Microclimate in Forest Ecosystem and Landscape Ecology. *Bioscience*, 49(4), pp.288–297.

Corley, R.H.V. & Tinker, P.B., 2003. *The Origin and Development of the Oil Palm Industry, in The Oil Palm* 4rth ed., Blackwell Science. Ltd, Oxford, UK.

Curran, L.M. & Paoli, G.D., 1999. Impact of El Niño and Logging on Canopy Tree Recruitment in Borneo. *Science*, 286(December), pp.2184–2188.

Dayamba, S.D. et al., 2016. Biodiversity and carbon stocks in different land use types in the Sudanian Zone of Burkina Faso, West Africa. *Agriculture, Ecosystems & Environment*, 216, pp.61–72.

Dobrowski, S.Z., 2011. A climatic basis for microrefugia: The influence of terrain on climate. *Global Change Biology*, 17(2), pp.1022–1035.

Drescher, J. et al., 2016. Ecological and socio-economic functions across tropical land use systems after rainforest conversion. *Phil. Trans. R. Soc. B 371: 20150275*.

FAO, 2012. *State of the World 's Forests*, Food and Agricultural Organization of the United Nations. Available at: http://www.fao.org/docrep/016/.

FAOSTAT, 2016. Data. Available at: http://faostat.fao.org/ [Accessed April 25, 2016].

Fitzherbert, E.B. et al., 2008. How will oil palm expansion affect biodiversity? *Trends in Ecology and Evolution*, 23(10), pp.538–545.

Foster, W.A. et al., 2011. Establishing the evidence base for maintaining biodiversity and ecosystem function in the oil palm landscapes of South East Asia. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*, 366(1582), pp.3277–91.

Frey, S.J.K. et al., 2016. Spatial models reveal the microclimatic buffering capacity of old-growth forests. *Science Advances*, 2(4), pp.1–9.

Glantz, M.H., Katz, R.W. & Nicholls, N., 1991. Teleconnections linking worldwide climate anomalies. *Cambridge University press*.

Gouyon, A., De foresta, H. & Levang, P., 1993. Does Jungle Rubber Deserve Its Name - an Analysis of Rubber Agroforestry Systems in Southeast Sumatra. *Agroforestry Systems*, 22(3), pp.181–206.

Guo, L.B. & Gifford, R.M., 2002. Soil carbon stocks and land use change: A meta analysis. *Global Change Biology*, 8(4), pp.345–360.

Hansen, M.C. et al., 2013. High-Resolution Global Maps of 21st-Century Forest Cover Change. *Science*, 342(6160), pp.850–853.

Hardwick, S.R. et al., 2015. The relationship between leaf area index and microclimate in tropical forest and oil palm plantation: Forest disturbance drives changes in microclimate. *Agricultural and Forest Meteorology*, 201, pp.187–195.

Harger, J.R.E., 1995. Air-temperature variations and ENSO effects in Indonesia, the Philippines and El Salvador. ENSO patterns and changes from 1866-1993. *Atmospheric Environment*, 29(16), pp.1919–1942.

Jackson, R.B. et al., 2008. Protecting climate with forests. *Environmental Research Letters*, 3, pp.1–6.

Jiang, J.-S.J.S. & Wang, R.-S.R.S., 2003. Hydrological eco-service of rubber plantations in Hainan Island and its effect on local economic development. *Journal of Environmental Sciences*, 15(5), pp.701–709.

Laumonier, Y. et al., 2010. Eco-floristic sectors and deforestation threats in Sumatra: identifying new conservation area network priorities for ecosystem-based land use planning. *Biodiversity and Conservation*, 19(4), pp.1153–1174.

Luskin, M.S. & Potts, M.D., 2011. Microclimate and habitat heterogeneity through the oil palm lifecycle. *Basic and Applied Ecology*, 12(6), pp.540–551.

Margono, B.A. et al., 2014. Primary forest cover loss in Indonesia over 2000–2012. *Nature Climate Change*, 4(June), pp.1–6.

Marshall, C.H. et al., 2004. The Impact of Anthropogenic Land-Cover Change on the Florida Peninsula Sea Breezes and Warm Season Sensible Weather. *Monthly Weather Review*, 132, pp.28–52.

McGregor, G.R. & Nieuwolt, S., 1998. *General Circulations of the Tropics, in the Tropical Climatology* 2nd ed., John Wiley and Sons ltd, Chichester, England.

Ni, Y. et al., 2016. The global potential for carbon capture and storage from forestry. *Carbon Balance and Management*, 11(1), pp.1–8.

Peng, S.-S. et al., 2014. Afforestation in China cools local land surface temperature. *PNAS*, 111(8), pp.2915–2919.

Randow, C. von et al., 2004. Comparative measurements and seasonal variations in energy and carbon exchange over forest and pasture in South West Amazonia. *Theoretical and Applied Climatology*, 78(1-3), pp.5–26.

Sanderson, M. et al., 2012. *Relationships between forests and weather*, Available at: http://ec.europa.eu/environment/forests/pdf/EU_Forests_annex1.pdf.

Trenberth, K.E., 1997. The Definition of El Niño. *Bulletin of the American Meteorological Society*, 78(12), pp.2771–2777.

Varotsos, C.A., Tzanis, C.G. & Sarlis, N. V., 2016. On the progress of the 2015–2016 El Niño event. *Atmospheric Chemistry and Physics*, 16(4), pp.2007–2011.

Wich, S.A. & Schaik, C.P. Van, 2000. The impact of El Niño on mast fruiting in Sumatra and elsewhere in Malesia. *Journal of Tropical Ecology*, 16(4), pp.563–577.

Williams, J. et al., 1983. The influence of texture, structure and clay mineralogy on the soil moisture characteristic. *Australian Journal of Soil Research*, 21(1), pp.15–32.

Yang, R. et al., 2016. Mapping Soil Texture Based on Field Soil Moisture Observations at a High Temporal Resolution in an Oasis Agricultural Area. *Pedosphere*, 26(5), pp.699–708.

Zerbo, I. et al., 2016. Effects of Climate and Land Use on Herbaceous Species Richness and Vegetation Composition in West African Savanna Ecosystems. *Journal of Botany*, 2016, pp.1–12.

7. Appendix

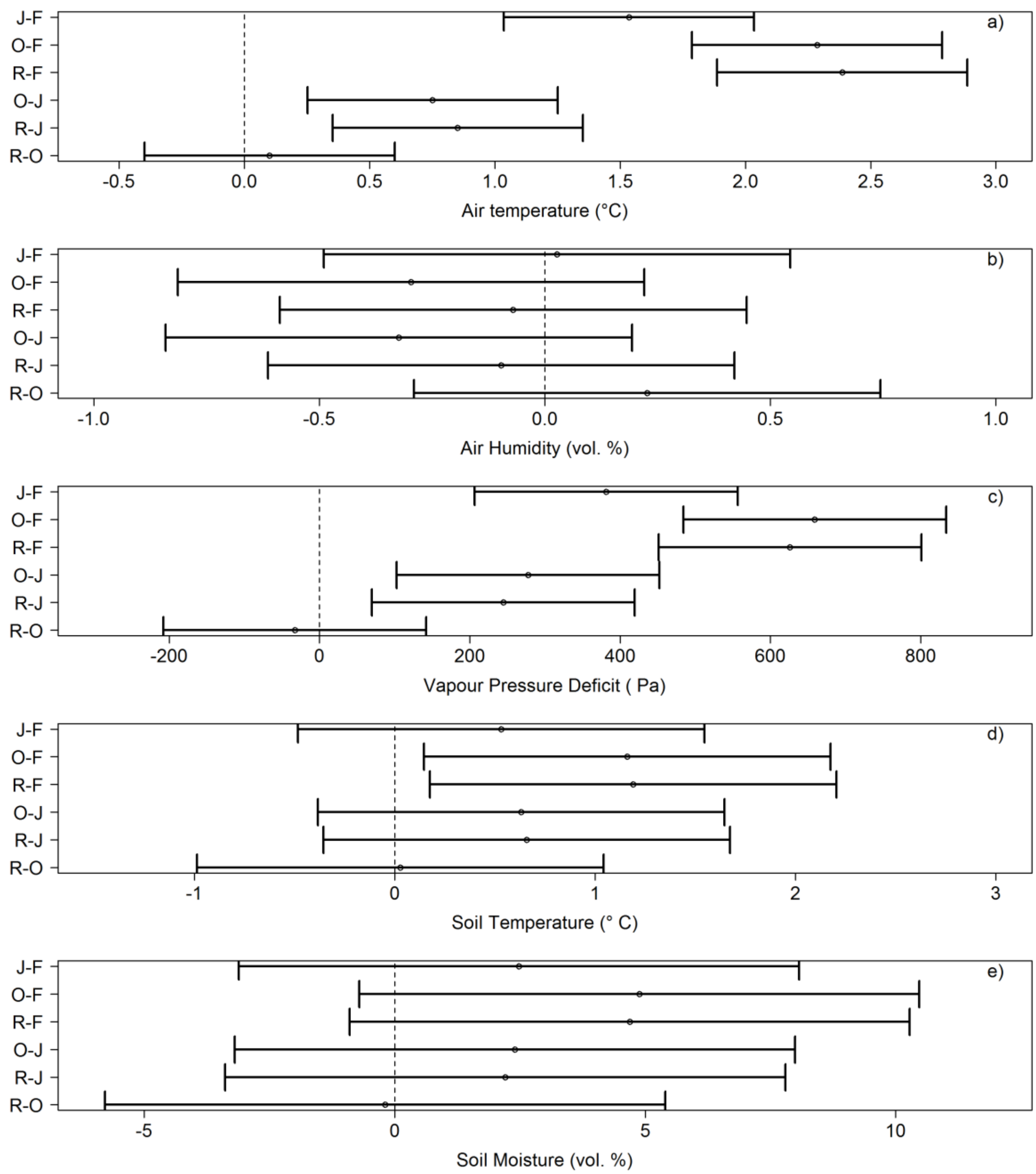
Appendix 1: Land-use types and geographical coordinates of core plots and meteo-stations in Bukit Duabelas (BD) and Harapan (HR) landscapes.

Plot type	Landscape	Code	Land-use	Latitude	Longitude
Core plot	BD	BF1	Forest	S 01°59'42.5"	E 102°45'08.1"
Core plot	BD	BF2	Forest	S 01°58'55.1"	E 102°45'02.7"
Core plot	BD	BF3	Forest	S 01°56'33.9"	E 102°34'52.7"
Core plot	BD	BF4	Forest	S 01°56'31.0"	E 102°34'50.3"
Core plot	BD	BJ2	Jungle rubber	S 02°01'49.7"	E 102°46'16.7"
Core plot	BD	BJ3	Jungle rubber	S 02°03'46.7"	E 102°48'03.5"
Core plot	BD	BJ4	Jungle rubber	S 02°00'57.3"	E 102°45'12.3"
Core plot	BD	BJ5	Jungle rubber	S 02°08'35.6"	E 102°51'04.7"
Core plot	BD	BR1	Rubber	S 02°05'30.7"	E 102°48'30.7"
Core plot	BD	BR2	Rubber	S 02°05'06.8"	E 102°47'20.7"
Core plot	BD	BR3	Rubber	S 02°05'43.0"	E 102°46'59.6"
Core plot	BD	BR4	Rubber	S 02°04'36.1"	E 102°46'22.3"
Core plot	BD	BO2	Oil palm	S 02°04'32.0"	E 102°47'30.7"
Core plot	BD	BO3	Oil palm	S 02°04'15.2"	E 102°47'30.6"
Core plot	BD	BO4	Oil palm	S 02°03'01.5"	E 102°45'12.1"
Core plot	BD	BO5	Oil palm	S 02°06'48.9"	E 102°47'44.5"
Core plot	HR	HF1	Forest	S 02°09'09.9"	E 103°21'43.2"
Core plot	HR	HF2	Forest	S 02°09'29.4"	E 103°20'01.5"
Core plot	HR	HF3	Forest	S 02°10'30.1"	E 103°19'57.8"
Core plot	HR	HF4	Forest	S 02°11'15.2"	E 103°20'33.4"
Core plot	HR	HJ1	Jungle rubber	S 01°55'40.0"	E 103°15'33.8"
Core plot	HR	HJ2	Jungle rubber	S 01°49'31.9"	E 103°17'39.2"
Core plot	HR	HJ3	Jungle rubber	S 01°50'56.9"	E 103°17'59.9"
Core plot	HR	HJ4	Jungle rubber	S 01°47'07.3"	E 103°16'36.9"
Core plot	HR	HR1	Rubber	S 01°54'39.5"	E 103°16'00.1"
Core plot	HR	HR2	Rubber	S 01°52'44.5"	E 103°16'28.4"
Core plot	HR	HR3	Rubber	S 01°51'34.8"	E 103°18'02.1"
Core plot	HR	HR4	Rubber	S 01°48'18.2"	E 103°15'52.0"
Core plot	HR	HO1	Oil palm	S 01°54'35.6"	E 103°15'58.3"
Core plot	HR	HO2	Oil palm	S 01°53'00.7"	E 103°16'03.6"
Core plot	HR	HO3	Oil palm	S 01°51'28.4"	E 103°18'27.4"
Core plot	HR	HO4	Oil palm	S 01°47'12.7"	E 103°16'14.0"
Meteo-station	HR	Bungku	Village	S 01°54'06.5"	E 103°15'08.0"

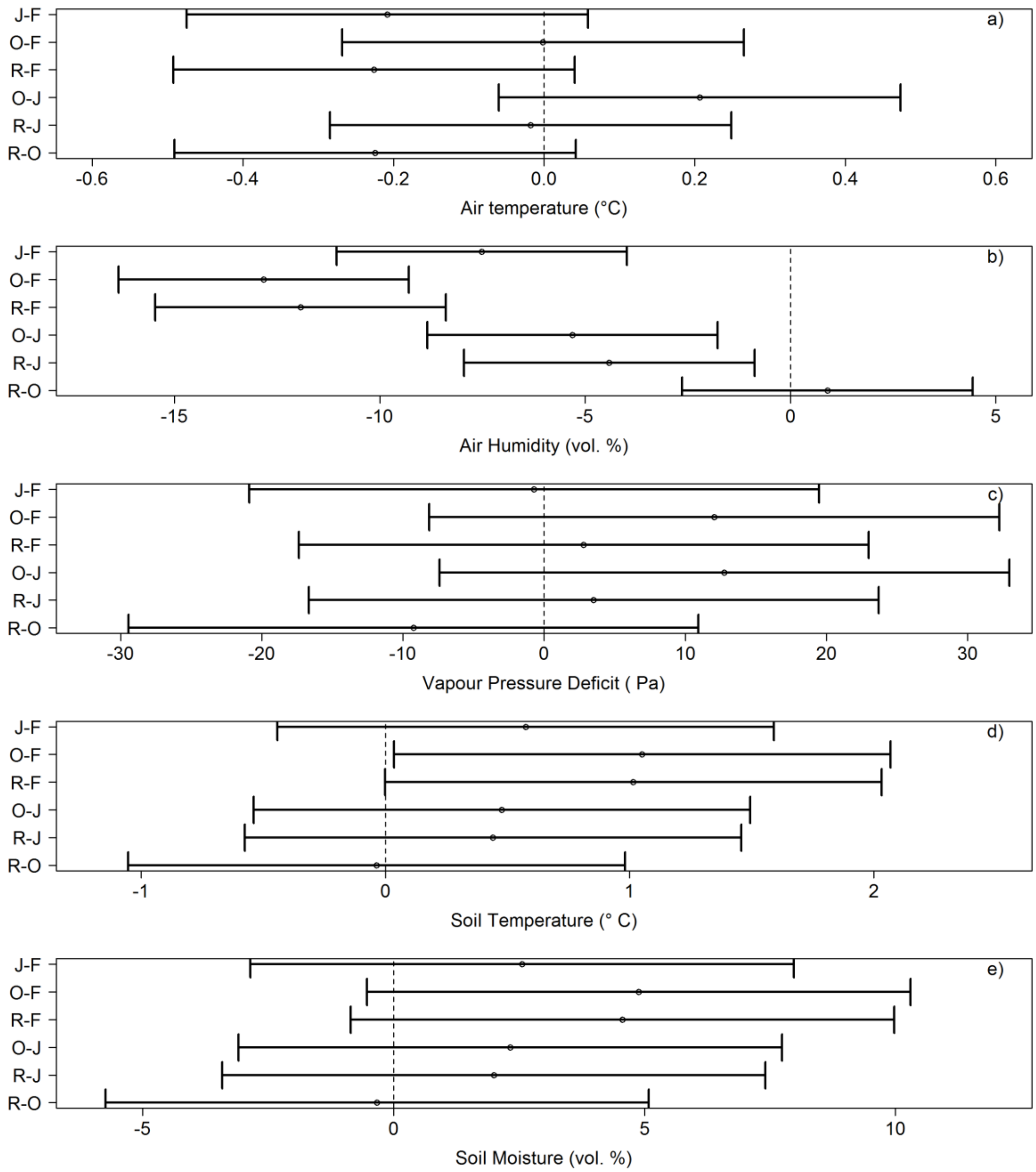
Meteo-station	HR	PT REKI	Forest	S 02°07'34.2"	E 103°22'08.5"
Meteo-station	BD	L. Kepayang	Village	S 02°05'17.6"	E 102°46'03.1"
Meteo-station	BD	P. Kabau	Village	S 01°57'58.7"	E 102°36'05.1"

(Drescher et al. 2016)

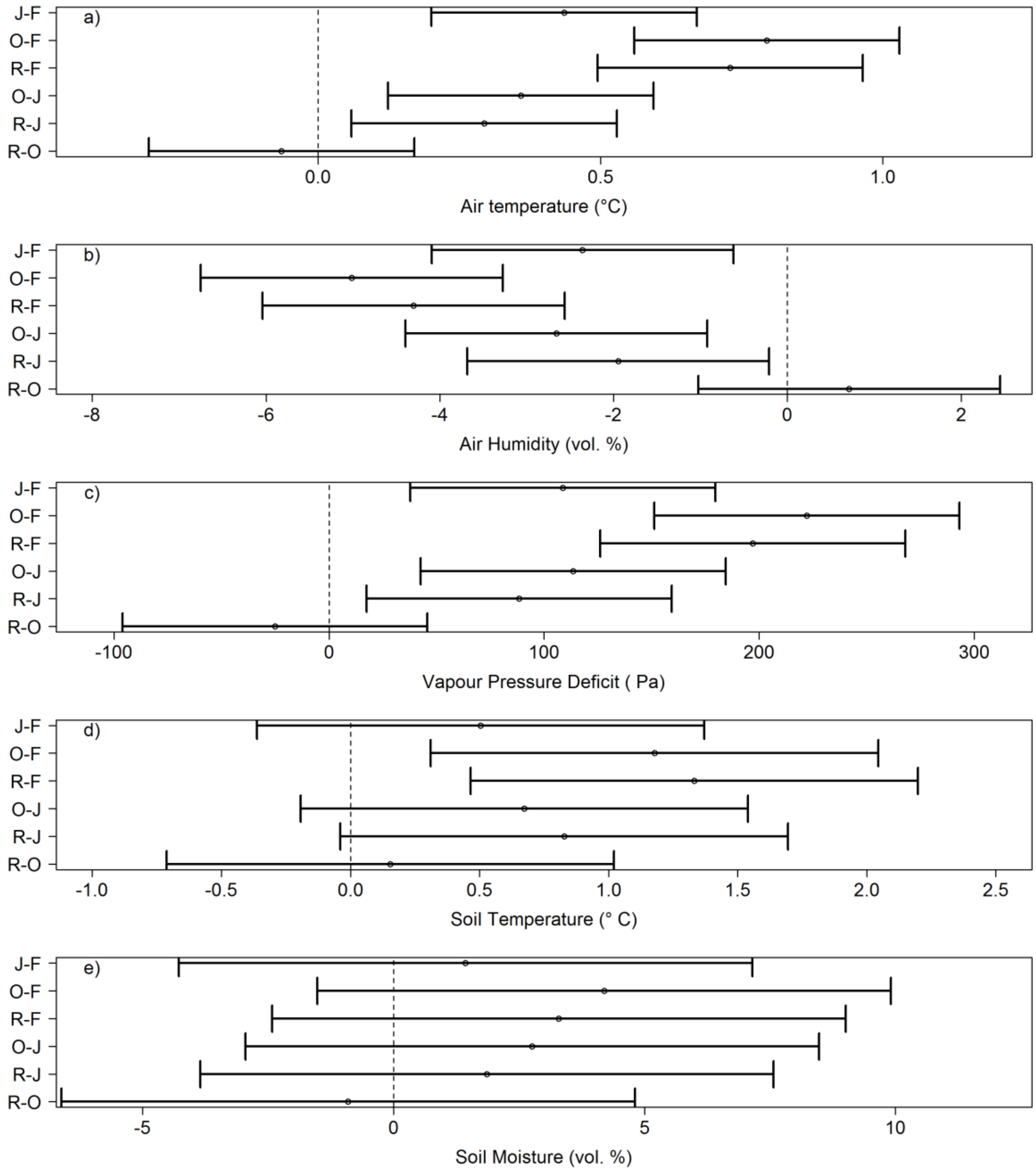
Appendix 2: Result from the Tukey HSD test with land-use systems differing with each other in the mean value of maximum a) air temperature, b) air humidity, c) vapour pressure deficit, d) soil temperature and e) soil moisture.



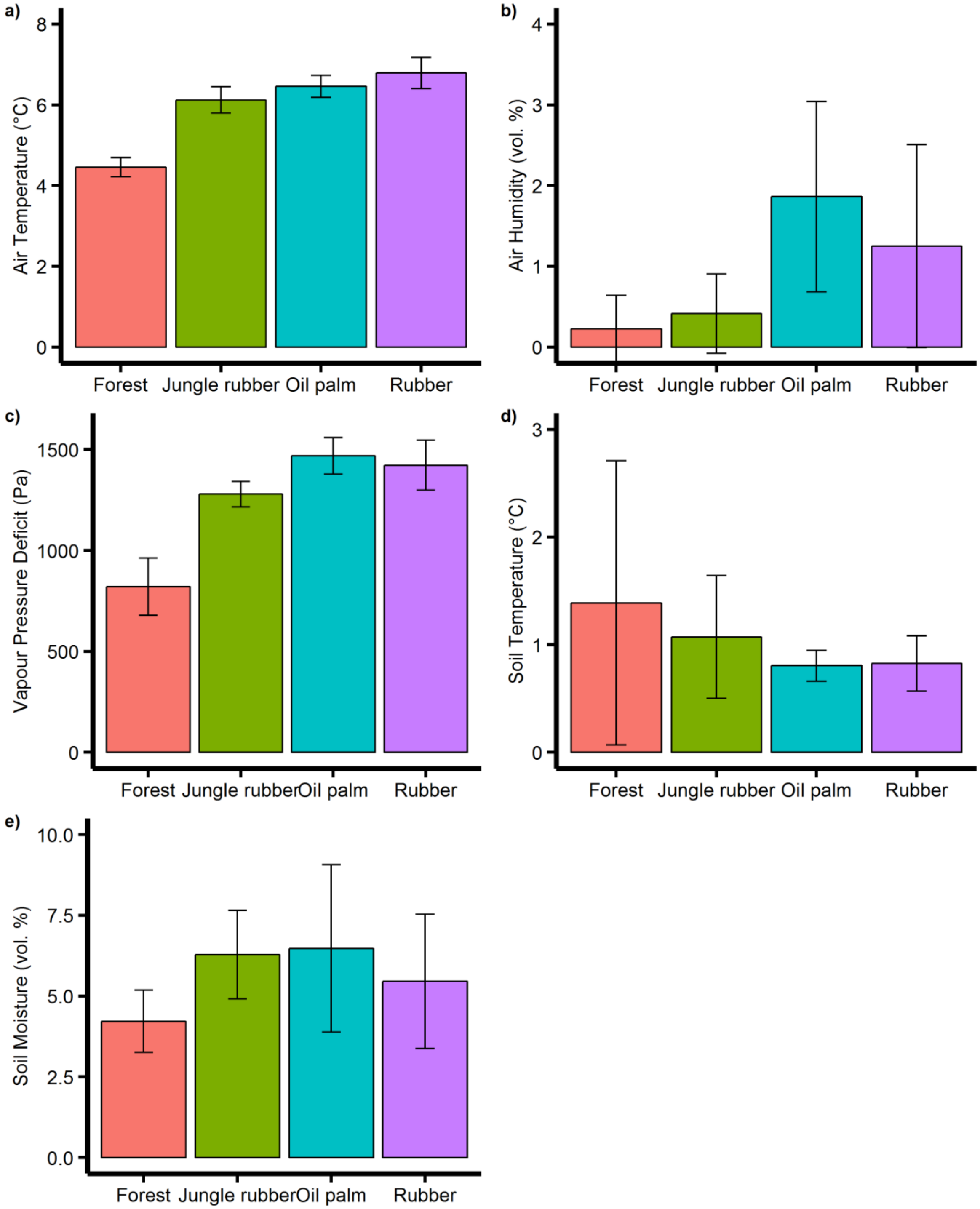
Appendix 3: Result from the Tukey HSD test with land-use systems differing with each other in the mean value of minimum a) air temperature, b) air humidity, c) vapour pressure deficit, d) soil temperature and e) soil moisture.



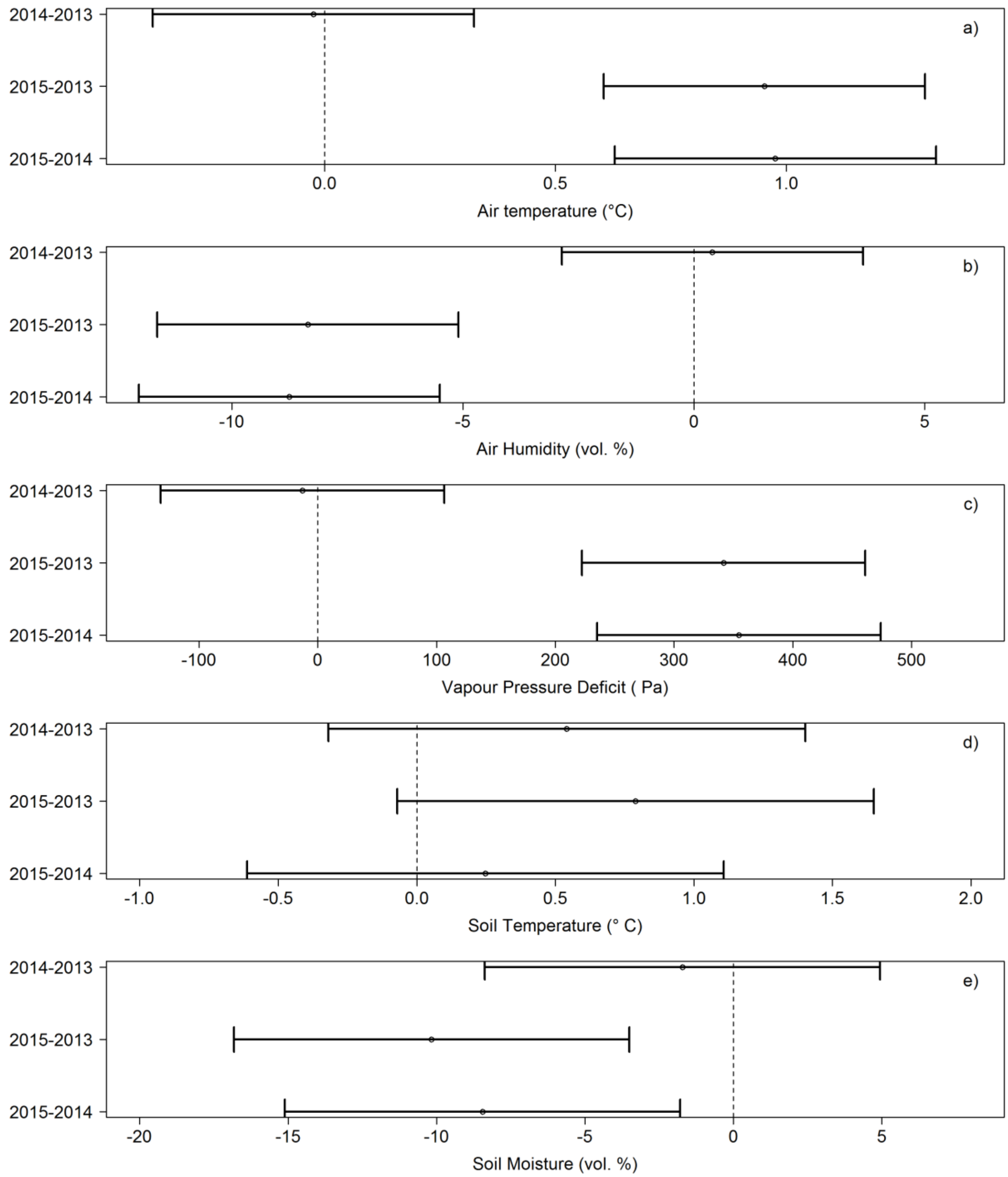
Appendix 4: Result from the Tukey HSD test with land-use systems differing with each other in the mean value of the difference between land-use systems and reference stations of a) air temperature, b) air humidity, c) vapour pressure deficit, d) soil temperature and e) soil moisture.



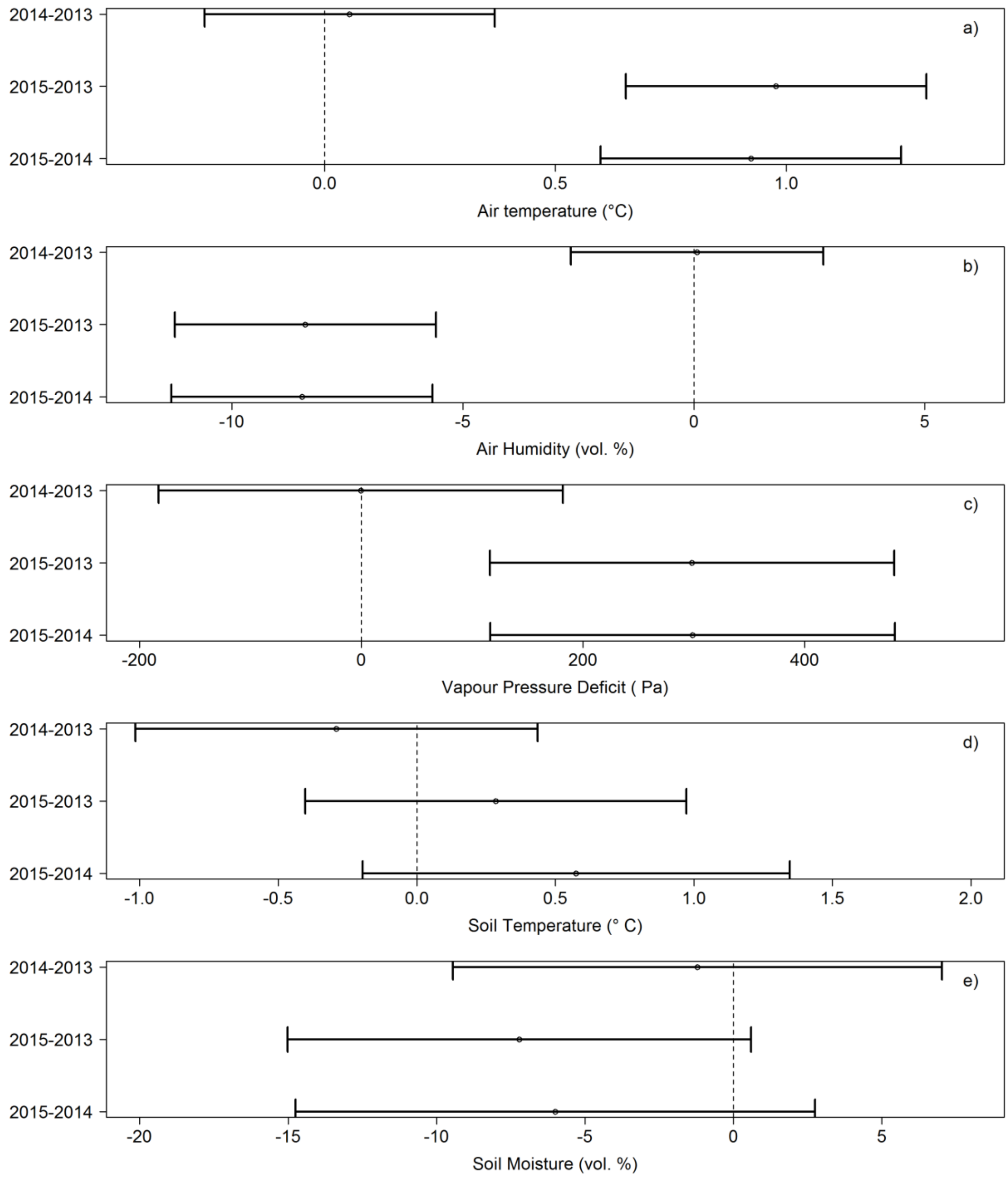
Appendix 5: The overall mean of the difference between 95 percentile and 5 percentile of a) air temperature, b) relative air humidity, c) vapour pressure deficit, d) soil temperature and e) soil moisture. Lines over bars represent the margin of error at 95% confidence interval.



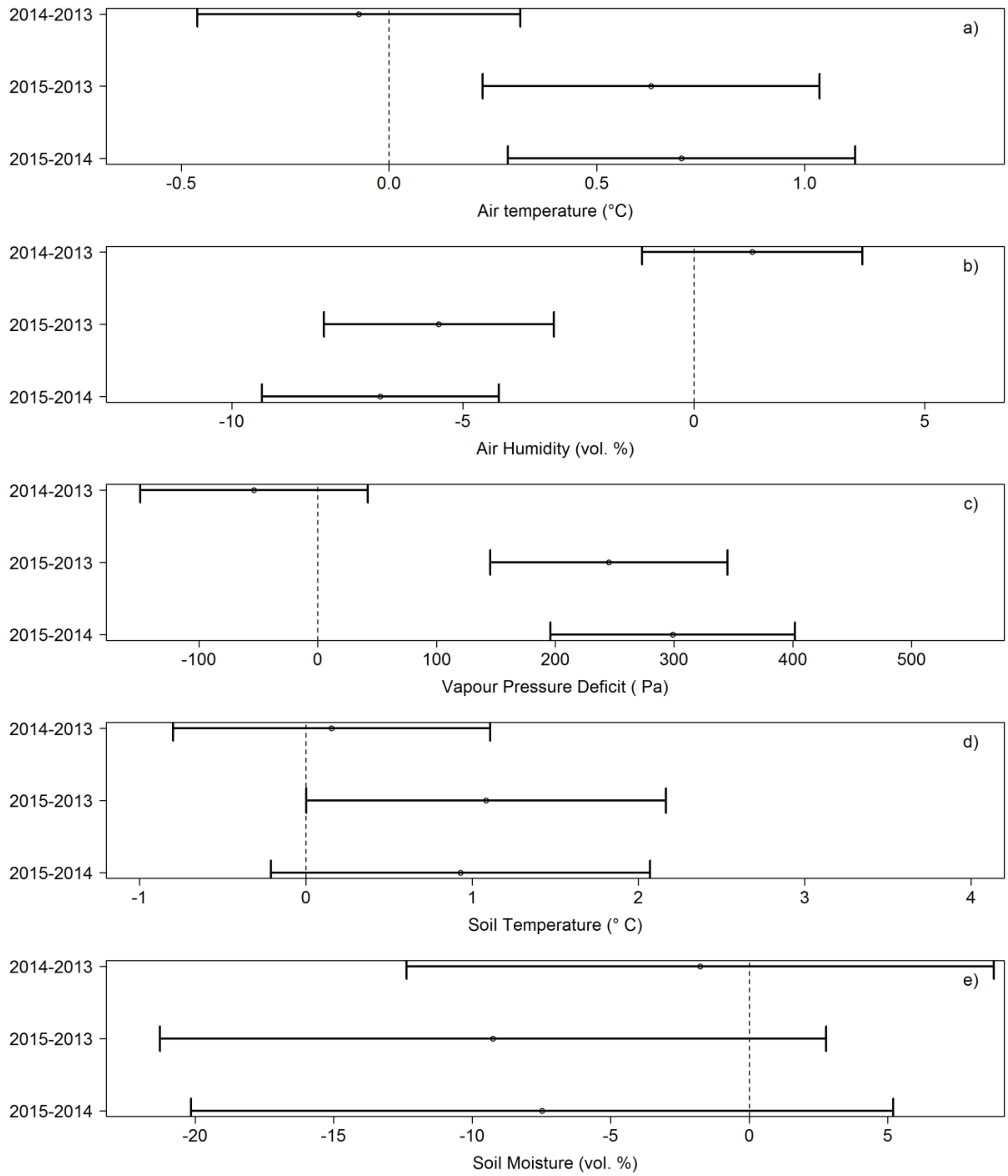
Appendix 6: Result from the Tukey HSD test showing years with a significant difference in the mean value of a) air temperature, b) relative air humidity, c) vapour pressure deficit, d) soil temperature and e) soil moisture of dry months of 2013, 2014 and 2015 of the forest.



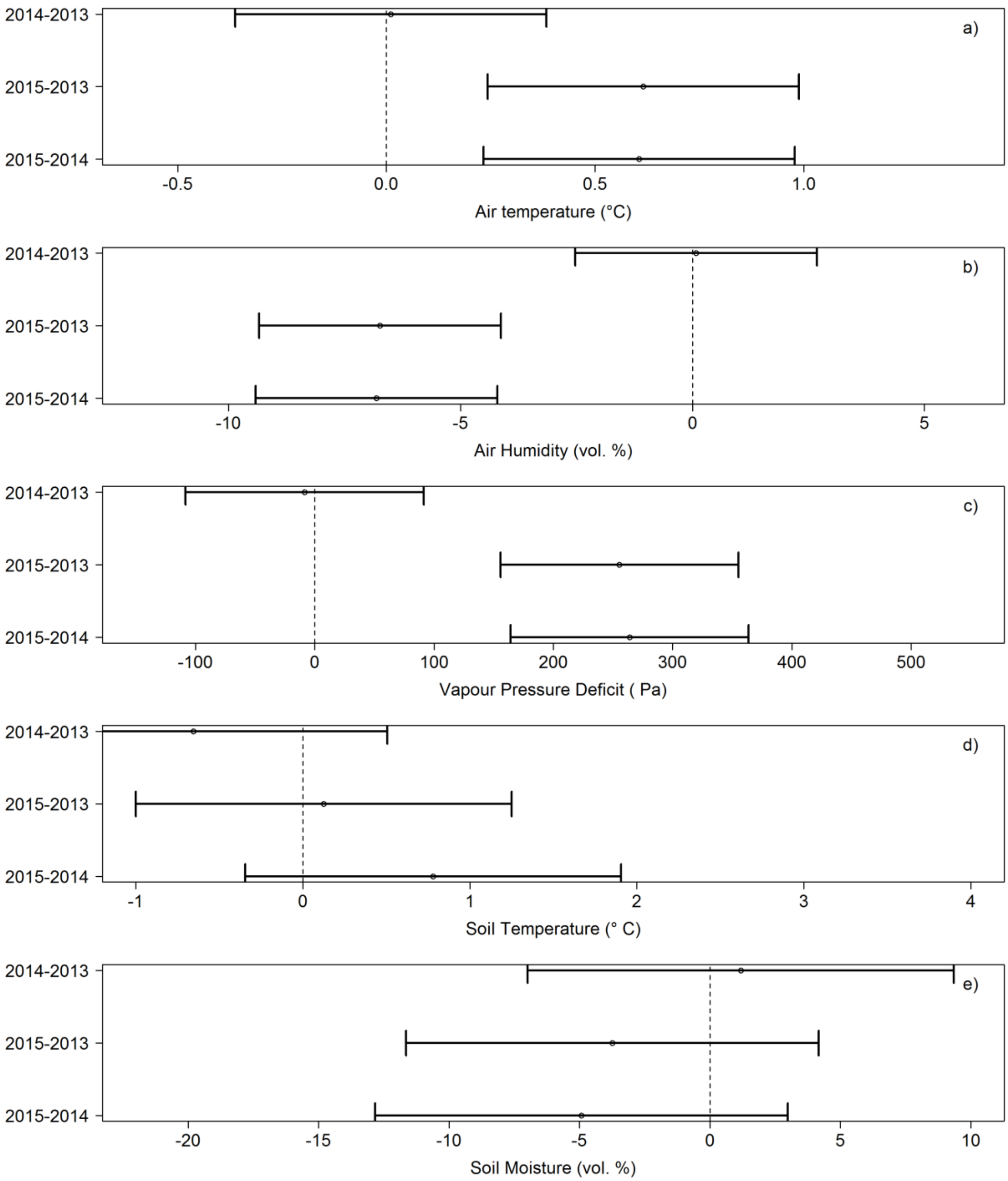
Appendix 7: Result from the Tukey HSD test showing years with a significant difference in the mean value of a) air temperature, b) air humidity, c) vapour pressure deficit, d) soil temperature and e) soil moisture of dry months of 2013, 2014 and 2015 of jungle rubber.



Appendix 8: Result from the Tukey HSD test showing years with a significant difference in the mean value of a) air temperature, b) air humidity, c) vapour pressure deficit, d) soil temperature and e) soil moisture of dry months of 2013, 2014 and 2015 of oil palm plantation.



Appendix 9: Result from the Tukey HSD test showing years with a significant difference in the mean value of a) air temperature, b) air humidity, c) vapour pressure deficit, d) soil temperature and e) soil moisture of dry months of 2013, 2014 and 2015 of rubber plantation.



8. Statement of declaration

I hereby assure that this thesis is the result of my own work and investigations, except where otherwise stated. This work has not been submitted before to any other university for any kind of degree.

Signed: ……………….. (Chandra Shekhar Badu)

Date: 21 November, 2016