Effects of Surface Soil Temperature on Cassava Physiology under Different Water Regimes

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Abstract

The effect of surface soil temperature on cassava physiological characteristics under different water regimes was studied. The aim of this research was to study the relationship between the surface soil temperature and cassava physiological characteristics under irrigated and non-irrigated conditions. The field experiment plots were conducted in Khon Kaen province. The surface soil temperatures and plant physiology during the three to five months after growing were measured using infrared thermography and Licor 6400XT, respectively. The data were then compared and correlated between different water regimes. The results showed that the surface soil temperature of the non-irrigated plot was higher than the irrigated plot. A negative correlation was observed among surface soil temperature, net photosynthesis, stomatal conductance and transpiration rate. However, the positive correlation between the surface soil temperature, the air vapor pressure deficit and the leaf temperature were detected. The critical of surface soil temperature affected to the cassava physiological characteristics was at about 30°C. When the surface soil temperature increased more than 30°C, the air vapor pressure deficit and the leaf temperature increased, while the net photosynthesis, stomata conductance and transpiration rate were gradually decreasing. Therefore, the surface soil temperature was an important factor affecting cassava physiology and growth development. Water and soil management, therefore could reduce surface soil temperature in hot season and leading to good growth development and yield increasing.

Keywords: Infrared thermography, Cassava, Plant physiology, Surface soil temperature

Introduction

Cassava (*Manihot esculenta*), a tuber and economic crop is importance cash crop for small farmers in Thailand. The crop is also used as raw material for the ethanol production in the country. Cassava is a drought tolerance crop and can be grown on various soil types, including the non-suitable soil such as extremely clayey or sandy soils and low fertility soils (Sawatdikarn, 2 014). In Thailand, suitable areas for cassava growth are on sandy loam and clay loam upland and well drained soils and with 50 cm or more surface soil depth for the cassava storage root development. Soil reactions vary from strongly acid to neutral. Cassava can be grown in the areas receiving less than 600 mm rainfall year^{-1} in the semiarid tropics, with a dry period of 4 to 6 months during harvest time. Critical period of cassava water demand is 1 to 5 months after planting, the stages of root initiation and tuberization. During this period if water deficit continuously for 2 months period, cassava storage root yield may reduce from 32 to 60 % (Hillocks, Thresh, & Bellotti, 2 0 0 2 ; Department of Agronomy, 2004).

Soil temperature could be effected to the root length, root dry weight, seed germination, root activity, plant nutrient absorption, decomposition of the organic and inorganic matters, and including the activity of soil organisms. The effect of low soil temperature was the decreasing of the stomata conductance and net photosynthesis (Lahti et al., 2002), and including decreases plant water absorption and finally wilt development. Optimum soil temperature for most plant growth was 15-40 °C, and the optimum soil temperature for root development was 24-27 °C. Excessively higher or lower of the soil temperature effected the metabolism processes and decreased plant growth (Department of Soil Science, 2005). In cassava, the optimal soil temperature was 30 °C, the temperature less than 10 °C prohibit growth (FAO, 2000). Optimal of soil temperature for cassava germination and stem development stage of the cultivar MAus7 and MAus10 were 28.5 and 30.0 °C, respectively (Keating & Evenson, 2003). Plant root continuous grown when the soil temperature was slightly higher. But when the temperature in the root zone was higher the stem plant inhibited the plant growth (Techawongstien, n.d.). Generally, both of root development and soil temperature are increased to the critical point, after the root development is reduced. The variation of soil temperature depends on the solar radiation, soil surface cover, soil type, soil water content and soil color. Sandy soil has higher temperature than the loamy and clay soils (Department of Plant Science, 2000). Moreover, the soil temperature of non-irrigated plots were higher temperature than the irrigated plots (McMichael & Burke, 1998).

Soil temperature measurement could be directly measured in the ground using thermometer or soil temperature sensors at different soil depth from the soil surface. Indirect measurement of the soil temperature under this research was conducted using remote sensing technology and thermal infrared camera (FLIR E50) for measurement of the surface soil and plant canopy temperatures. The thermal infrared camera has an accuracy of only around ± 2 °C. The aim of this research was to analyze the correlation of the surface soil temperature and physiological characteristic of cassava under irrigated and non-irrigated condition.

Methods and Materials

Cassava (*Manihot esculenta* cv. Rayong 9) was planted in the field experimental of Khon Kaen University (16° 28′ 25″ N, 102° 48′ 34″ E) on the late rainy season (November 2015) under irrigated and non-irrigated conditions. The irrigated plots were supplied by the sprinkler water over the cassava fields and maintained the soil moisture potential not less than -30 kPa at 20 cm depth from the soil surface. The non-irrigated plots were supplied water during the cassava planting to 20 days after planting (DAP), after this period the cassava received only from rainwater. Complete Randomized Design (CRD) with three replications were designed for this experiment, as a row space of 1 meter and plant space of 1 meter in the plot size of 28 x 7 sq m^{-1} (2.30 ha). Soil texture of the field experiment was sandy loam (sand 57%, silt 31%, clay 12%). The average 5 years (2011-2015) of weather data from the nearby Northeastern Meteorological Center found that the annual rainfall was 1,088 mm, the average maximum and minimum temperature were 32°C and 23°C respectively, and the average air relative humidity was 70%. A weather station was also installed in the field experiment to record rainfall, air temperature, air relative humidity and solar radiation. Soil moisture sensor was embedded at 20 cm-depth from the soil surface to monitor the soil moisture potential and for scheduling water supply.

Surface soil temperature (T_{soil}) was measured by using thermal infrared camera (FLIR E50, wavelength 7.5-14 μm) above the cassava canopy, 1.5 m and on the ground, 0.67 m. at midday (11am-2pm), under clear sky. Wind speeds were measured. Cassava tree diameters were captured twice a month at the cassava aged of 3 to 5 months after plating (February to April 2016) which was the critical period for water deficit and would effect to the storage root yield. (Hillocks et al., 2002). Plant physiology were measured to the fully expand leaves by Licor 6400XT, and also immediately collected after captured thermal imaging of the cassava tree. After that, the thermal imaging was analyzed using FLIR Tools software. The emissivity value and the distance between camera and plant were set at 0.95 and 1.5 m, respectively. T_{soil} was randomly selected 3 values from the thermal imaging under the bare soil, no cover and shade of the plant. Statistical analysis was significantly tested using *t*-test between the treatments ($p<0.05$). The correlation analysis between T_{soil} and plant physiology were analyzed using R (R Development Core Team, 2017).

Results

Weather and soil moisture data of the field experiment

The collected weather data during the cassava growth were the daily data of rainfall, air temperature, air relative humidity and solar radiation as show in Figure1. The average solar radiation was 437 MJ m^{-2}, minimum air temperature was 9°C, and maximum air temperature was 44°C. The average air temperature was 36°C, air relative humidity was 48%, and the total rainfall during the field measurement was 108 mm. The soil moisture of irrigated plots were maintain at -30 kPa during the 85 to 163 DAP and for the non-irrigated plots were -9.9 and -24.6 kPa, respectively.

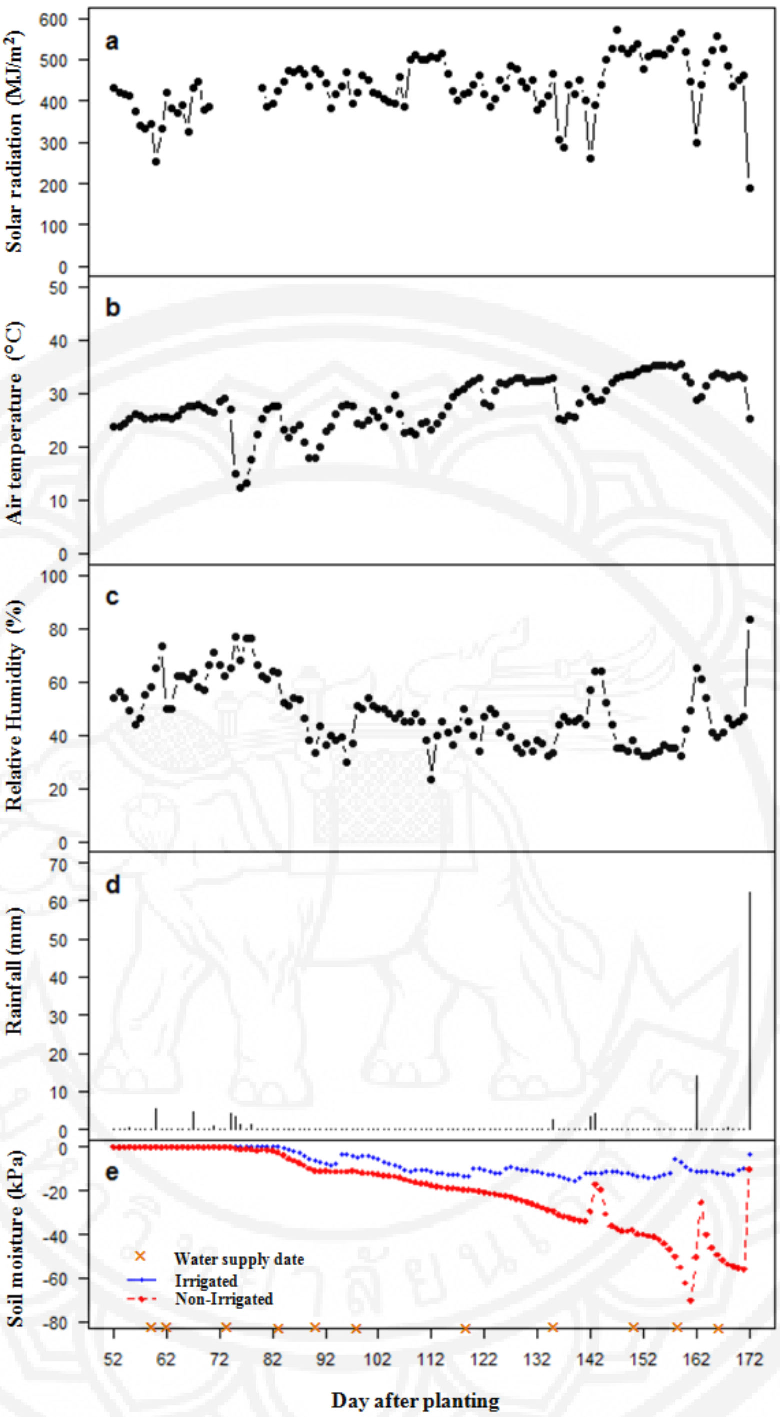

Figure 1 Daily data of the weather and soil moisture in the field experiment during field measurement.

Surface soil temperature

The surface soil temperatures under the cassava tree during the 85 to 163 DAP were measured. The average of T_{soil} between irrigated and non-irrigated were increased in the same direction trend. T_{soil} of the non-irrigated plots were significantly higher than the irrigated plot during the field measurement. T_{soil} at 163 DAP was dropped as affected by the rainfall (Figure 1d). The average of T_{soil} in the irrigated and non-irrigated plot were 30.5 and 39.7°C, respectively (Figure 2). T_{soil} of the irrigated plot at the early and late measurement was less than 30°C as the result of the water supply (Figure 1e). The air temperature of the irrigated plots were less than 30°C (Figure 1b). While, the T_{soil} of irrigated and non-irrigated plots at 128 and 148 DAP were more than 30°C, the air temperature more than 30°C, but the relative humidity were declined. (Figure 1b-c).

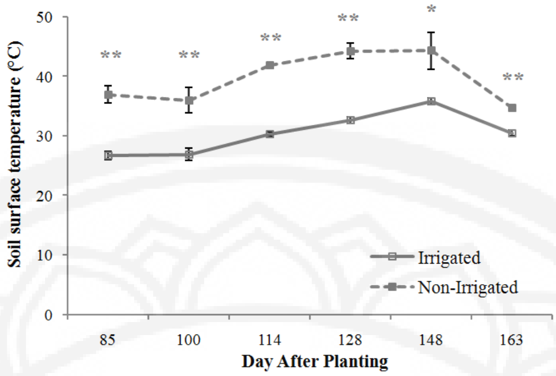

Figure 2 The average of surface soil temperature in the cassava irrigated and non-irrigated plot.

Plant physiological parameter

Net photosynthesis (P_N), stomatal conductance (g_s), air vapor pressure deficit (VPD_{air}), transpiration rate (E) and leaf temperature (T_{leaf}) of the cassava under the irrigated and non-irrigated plots at 85 to 163 DAP were measured. P_N, g_s and E of the irrigated plots were higher than the non-irrigated plots, whereas the VPD_{air} and T_{leaf} of the irrigated plots were lower than the non-irrigated plots. The average P_N of irrigated and non-irrigated plots were 23.60 and 17.18 µmolCO_2 $m^{-2}s^{-1}$. The average g_s of the irrigated and non-irrigated plots were 320.96 and 153.17 mmolH_2O $m^{-2}s^{-1}$. The average E of the irrigated and non-irrigated plots were 8.57 and 6.15 mmolH_2O $m^{-2}s^{-1}$. The average VPD_{air} of the irrigated and non-irrigated plots were 3.53 and 4.56 kPa. The average T_{leaf} of the irrigated and non-irrigated plots were 35.9 and 38.4 °C. At 114 DAP (4 months old) found a significance different between the irrigated and non-irrigated plots of the overall cassava physiological characteristic (Table 1), the period of the non-irrigated for 15 days and no rainfall were effected (Figure 1d-e). At the age of 128 and 148 DAP, cassava showed no significance different of the overall physiological characteristic between the irrigated and the non-irrigated plots. However, the average of air temperature was more than 30°C, the non-significance different of physiological characteristic, and also the highly significance different of T_{soil} was obtained. Therefore, the air temperature was the main factor to the significance different of the cassava physiology and T_{soil}.

Table 1 Effect of the irrigated and non-irrigated to the cassava physiological parameters.

Parameters	Treatments	Day after planting					
		85	100	114	128	148	163
P_N	Irrigated	21.15±2.28[1]	25.08±1.75	29.39±2.02a	18.82±2.67	18.43±2.00	28.76±0.12a
	Non-irrigated	18.71±4.35	19.53±3.79	14.67±4.87b	12.39±4.80	14.68±5.76	23.08±3.22b
	t-test	ns[2]	ns	**	ns	ns	*
	CV(%)	16.98	18.04	39.60	31.68	26.37	14.34
g_s	Irrigated	141.91±11.01a	382.50±61.13a	443.33±102.65a	276.76±76.60	136.96±32.59	544.32±32.43a
	Non-irrigated	86.94±23.61b	169.24±61.61b	120.86±66.91b	140.89±77.40	117.58±46.20	283.53±85.84b
	t-test	*	*	*	ns	ns	**
	CV(%)	30.00	46.78	68.38	48.56	29.31	37.25
VPD_{air}	Irrigated	3.59±0.11b	2.36±0.13	3.21±0.23b	4.77±0.35	5.39±0.13	1.89±0.12b
	Non-irrigated	4.33±0.29a	3.59±0.45	4.88±0.68a	5.87±0.85	6.07±0.60	2.63±0.30a
	t-test	*	ns	*	ns	ns	*
	CV(%)	11.43	24.65	25.27	15.75	9.29	20.14
E	Irrigated	4.86±0.26	8.15±0.89a	11.86±1.00a	11.05±1.79	7.19±1.26	8.30±0.64
	Non-irrigated	3.79±0.82	5.95±1.25b	5.89±2.00b	7.47±2.77	6.88±1.84	6.89±0.86
	t-test	ns	*	*	ns	ns	ns
	CV(%)	18.57	21.90	40.09	30.91	20.23	13.55
T_{leaf}	Irrigated	30.5±0.55b	32.7±0.55b	36.1±0.69b	40.2±0.55	40.2±0.23	35.6±0.51b
	Non-irrigated	33.1±0.41a	35.9±1.15a	39.9±1.60a	42.3±1.69	41.7±1.16	37.6±0.64a
	t-test	**	*	*	ns	ns	*
	CV(%)	4.59	5.71	6.11	3.85	2.77	3.31
T_{soil}	Irrigated	26.7±0.65b	26.9±1.01b	30.37±0.40b	32.7±0.57b	35.8±0.55b	30.5±0.47b
	Non-irrigated	36.9±1.45a	36.0±2.14a	41.87±0.06a	44.3±1.31a	44.4±3.06a	34.7±0.17a
	t-test	**	**	**	**	*	**
	CV(%)	17.88	16.53	17.45	16.61	12.65	7.06

Remarks

[1]Average ± Standard deviation (SD)

[2]The comparison of average valued using *t*-test at the 0.05 level, ns= not significant, *= significant at the 0.05 level, **= significant at the 0.01 level

P_N is the net photosynthesis (μmolCO_2 $m^{-2}s^{-1}$), g_s is the stomatal conductance (mmolH_2O $m^{-2}s^{-1}$), VPD_{air} is the air vapor pressure deficit (kPa), E is transpiration rate (mmolH_2O $m^{-2}s^{-1}$), T_{leaf} is the leaf temperature (°C), and T_{soil} is the surface soil temperature (° C).

Correlation of T_{soil} and cassava physiological parameters

The correlation between the T_{soil} and cassava physiological parameters under irrigated and non-irrigated plots were determined. The T_{soil} and the overall cassava physiological parameters were significance different. P_N, g_s, VPD_{air} and T_{leaf} under the irrigated and the non-irrigated plots were significance different at the 0.01 level. However, E under the irrigated and the non-irrigated plots were significance different at the 0.05 level. The negative correlations found were the T_{soil} and P_N, g_s, E, the coefficient of determination (R^2) 0.75, 0.79 and 0.21, respectively. The equations of P_N, g_s, E to predict T_{soil} were y = 48.4 - 0.781x, y = 799 - 15.5x and y = 12.7 - 0.137x, respectively. The positive correlations among the T_{soil} and the VPD_{air}, the T_{leaf} were detected at 0.88 and 0.87 of the R^2, respectively. The equations of the VPD_{air}, the T_{leaf} to estimate the T_{soil} were y = -3.01 + 0.196x และ y = 19.8 + 0.489x, respectively. The results showed that the T_{soil} increased as the effect of the VPD_{air} and T_{leaf} that were increased, while the P_N, g_s and E were declined (Figure 3).

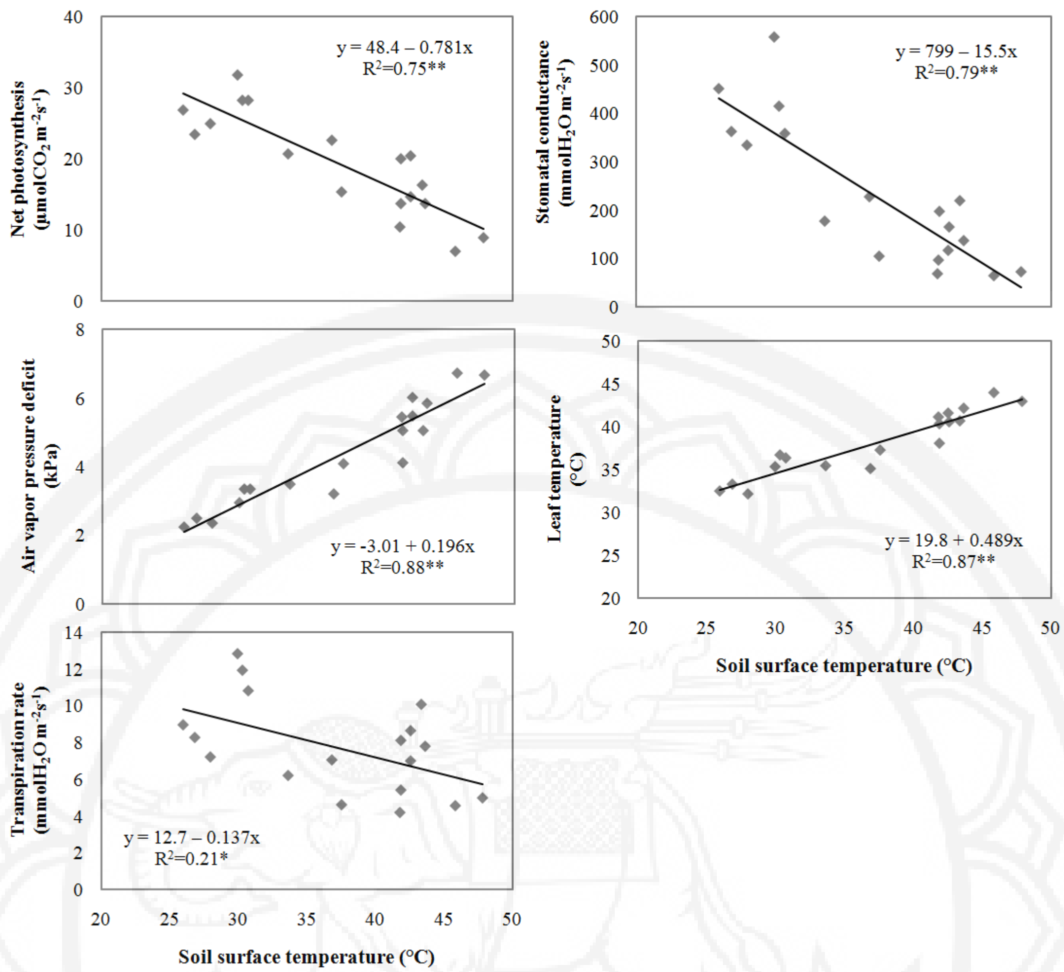

Figure 3 Correlation between surface soil temperature and cassava physiological parameters.

Discussion

Surface soil temperature is one of the importance factor to control the physiological of cassava. Negative correlation was found among the T_{soil} and the P_N g_s and E. However, the positive correlations among the T_{soil} and the VPD_{air}, the T_{leaf}. The T_{soil} and the VPD_{air} were highest correlations. The non-irrigated plots were higher T_{soil} than the irrigated plots. The T_{soil} of the irrigated and non-irrigated plots were 30.5 and 39.7 °C, respectively. At 85, 100, 114 and 163 DAP of cassava plantation, the average T_{soil} in the irrigated plots were less than 30 °C. The cassava physiology between the irrigated and non-irrigated plots showed significance different. At 128 and 148 DAP of cassava found that both of the irrigated and non-irrigated plots were T_{soil} higher than 30 °C, but not significantly different as the physiological parameter. This research was also found that the critical T_{soil} of cassava was 30 °C (FAO, 2000), that effected to the cassava physiology adaptation. When the T_{soil} increased, as the VPD_{air} and T_{leaf} increased, while the P_N, g_s and E were declined (El-Sharkawy & Cock, 1984). The lack of rainfall for a long period and T_{soil} higher than 30 °C were effected to the cassava physiology and reduced cassava growth (Department of Soil Science, 2005). In addition to the directly effect of the T_{soil} and cassava physiology, it was determined by the environmental factors such as air temperature, air relative humidity, and etc. The non-irrigated plots or plant water deficits had prospect to the high of T_{soil} than the irrigated plots. Irmak (2016) found that the increasing of T_{soil} was resulted from the air temperature increased, and that effected to the water movement rate from the soil to the root and stem systems, plant transpiration rate decreased, soil water content decreased, and also including the water and plant nutrient absorptions.

Therefore, farm management to control the T_{soil} was essential method. Mulching should be conducted to protect the directly sunlight during daytime, and to reduce the difference T_{soil} between the day and night times. Water supply and drainage should also be managed to increase the soil moisture. In addition plowing should be done for the soil transferred the heat to the lower soil profile and T_{soil} decreased (Department of Plant Science, 2000). Reducing of T_{soil} was effected to the continuous root growth of plant and more efficiency to the water and plant nutrient absorption (Irmak, 2016). These methods were also reduced the soil temperature at the different soil depth and helped the plants growth and yield to be more efficient.

Conclusion and Suggestion

Surface soil temperature and cassava physiological parameters under irrigated and non-irrigated plots during the 3-5 MAP was studied. The non-irrigated plots has higher T_{soil} than the irrigated plots. The negative correlation were found among the T_{soil} and P_N, g_s, E, and the positive correlations of the VPD_{air} and the T_{leaf}. When the T_{soil} increased, the VPD_{air} and T_{leaf} were also increased, and the decreasing of the P_N, g_s and E. The water supplies in the dry season to reduce the T_{soil} were necessary activity, and P_N, g_s and E were increased. The increased of the P_N, was significantly affected to the plant growth and yield. The application of thermal infrared camera could be used to rapidly and non-destructively measurements. However, other factors effected to the T_{soil} should be considered such as soil types, soil color, soil water content, light intensity and etc. The further studies should be conducted to assess the T_{soil} effected to the plant growth stage, soil temperature at various soil depth and crop yield. Moreover, this research could be used as a model to the other economic crops.

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