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Effect of Soil Moisture and Determination of Critical Soil Moisture Contents of Cassava

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ABSTRACT

The aims of this research were to investigate the effects of soil moisture on cassava growth and physiological processes and to determine the critical soil moisture contents. To fulifll the research objectives, cassava was grown under five levels of soil moisture, including 50, 40, 30 and 20% of soil available water holding capacity (AWHC) along with control (no irrigation). Physiological traits and plant growth parameters were measured. The results showed that cassava grown under 50% of AWHC exhibited the highest photosynthesis rate, stomatal conductance, predawn leaf water potential and chlorophyll activity. All physiological traits decreased significantly when the moisture content was less than 40 and 20% of AWHC in sandy clay loam and loamy sand soil, respectively. Predawn leaf water potential was used to determine the critical point of soil moisture. It was found that the critical soil moisture contents were 39.0 and 15.7% of AWHC in sandy clay loam and loamy sand soil, respectively.

Key words: Drip irrigation, Leaf water potential, Loamy sand, *Manihot esculenta*, Sandy clay loam soil, Water use efficiency.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is one of the most important economic crops in tropical countries, especially in Africa, South America and Asia. About two thirds of cassava production is used as food for humans, while other uses include for animals and industry. In Thailand, the planting areas of cassava rank fourth after rice, maize and rubber, while the harvest area was around 1.265 million hectares with a total production of 27.55 million tons (Office of Agricultural Economics, 2017). Thailand exported around 33 million tons of cassava products in 2016, which contributed to 67% of the global market (Thailand Board of Investment, 2017).

Irrigation is an essential water management tool for crop cultivation to form growth tissue in an active plant. Cassava is no exception, even though it is known to be a reasonably tolerant crop in terms of drought compared to cereals and other crops (Odubanjo *et al*., 2011; Oshunsanya and Nwosu, 2018). The amount, quality, frequency and method of water applied can affect the growth, starch content and yield of cassava (Olanrewaju *et al*., 2009), especially during a dry period, which can last for 5-6 months in Thailand (Aina *et al*., 2007). Piyachomkwan and Tanticharoen (2011) reported that cassava yield from rain-fed conditions was 20-25 tons/ha in Thailand, while cassava yield with irrigation was around 32.7-56.9 tons/ha (Samutthong, 2007). There are various irrigation systems for crop production e.g. flood irrigation, furrow irrigation, sprinkler and drip irrigation. Suitable irrigation system for dry area or water limited area is drip irrigation because of its benefit such as water saving (Kahlon, 2017), uniform application, easy management, low labor cost, decreased weed growth, increased crop yield and improved quality of crop product (Polthanee and Srisutham, 2018). Still, most cassava farmers in Thailand cannot manage drip irrigation effectively to increase their cassava productivity due to several reasons. The low quality of drip irrigation products in the market and incorrect installation by farmers has limited the efficiency of drip irrigation in agricultural fields. More importantly, many farmers cannot use water effectively due to lack of appropriate recommendations. Efficient irrigation means that a sufficient amount of water for plant requirements is met through maintaining soil moisture at a certain level between the field capacity (FC) and permanent wilting point (PWP). Tolk (2003) demonstrated that plant wilt could be induced when the soil moisture content decreased to PWP. Therefore, it is very risky for plants when soil moisture content decreases to near this point. In general, soil moisture content can decrease to the lowest point with no reduction in plant physiological processes or growth before the next irrigation application. This soil moisture is called critical soil moisture, which is roughly 50% of AWHC. Because cassava is a

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drought-tolerant crop, it may be able to grow under levels of moisture content lower than 50% of AWHC. The critical soil moisture level for the crops should be determined for accurate water supply. Soil texture is an important external factor for the quantification of irrigation water applied, while internal factors that affect the water used by plants are crop type, growth stage and depth and distribution of roots. Thus, the physiological response of plants to soil moisture and the critical moisture content of a specific crop may vary depending on different soil types, especially soil texture. Considering the above facts, the present study was, therefore, undertaken with the following objectives:

(i) To investigate the response of cassava to soil moisture contents and

(ii) To determine the critical soil moisture content for cassava in loamy sand and sandy clay loam soils.

MATERIALS AND METHODS

Experimental sites and crop variety

The experiment was conducted under greenhouse conditions at Suranaree University of Technology, Nakhon Ratchasima, Thailand. Two soils (loamy sand belonging to Ban Phai soil series and sandy clay loam belonging to Si Khiew soil series) were used for this research (Table 1). The AWHC of 7.3% (by volume) in loamy sand soil was less than that of 13.9% in sandy clay loam soil. Cassava var. Rayong 72 is the most popular variety in Thailand and has a high ability in the translocation of assimilation for the storage of starch in tuber roots (Polthanee *et al*., 2014). It was planted in 130 L plastic tanks (65 cm height and 50 cm diameter).

Experimental design

The experiment was laid out in a completely randomized design with 4 replications. Treatments consisted of 5 different irrigation levels including 50, 40, 30 and 20% of AWHC (%vol.) and no irrigation (control). The soil moisture content was measured to determine the irrigation level for each treatment (Table 2) using the profile probe version PR216. When soil moisture decreased to each treatment's level, drip irrigation was applied until regaining the FC.

Table 1: Physical characteristics of the both soils.

Soil series	Practical size distribution (%)			Soil texture
	Sand	Silt	Clay	
36[1]	88	9	3	Loamy sand
41[2]	68	15	17	Sandy clay loam

[1]Ban Phai soil series: Bpi, loamy, siliceous, isohyperthermic Arenic Paleustalfs.

[2]Si Khiew soil series: Si, series, Fine-loamy, mixed, isohyperthermic Typic Rhodustalfs.

Data collection

Physiological traits

The predawn leaf water potential (bar), photosynthesis rate (μmole $CO_2/m^2/s$) and stomatal conductance (mole $CO_2/m^2/s$) was determined using the fifth leaf from the top between 30-120 days after planting (DAP). Predawn leaf water potential (bar) was measured from 05.00-06.00 a.m. according to El-Sharkawy *et al*. (1987) using a pressure bomb. Photosynthesis rate (μmole $CO_2/m^2/s$) and stomatal conductance (mole $CO_2/m^2/s$) were determined using a photosynthesis meter LCi-SD from 08.30-09.30 a.m. according to El-Sharkawy *et al*. (2012). Both were used for calculation of chlorophyll activity.

Plant growth measurement

Plant height (cm) was measured from the base of the plant to the top part of the highest leaf. Stem girth (cm) was determined from a main stem around the middle of the plant height. Leaf area index (LAI) was calculated by ground area and leaf area as measured using a Li-cor area meter version Li-3100e at 4 months after planting (MAP). Total dry matter (TDM) was measured with plants oven-dried at 80°C for 48 hours at 4 MAP.

Statistical analysis

Analysis of variance for all parameters was performed using SPSS version 16 for Windows. Mean values were compared using Duncan's multiple range tests (P-value < 0.05). The multiple correlation coefficients between variables were determined.

RESULTS AND DISCUSSION

Response of the physiological traits of cassava to different levels of soil moisture content

The results showed that the physiological traits of cassava were influenced by drip-irrigated treatments (Table 3). They were positively correlated with the soil moisture content in soils. The highest photosynthesis rate, stomatal conductance, predawn leaf water potential and chlorophyll

Table 2: Available water holding capacity for loamy sand soil and sandy clay loam soil.

Available water holding capacity (AWHC)	Loamy sand soil (%vol)	Moisture content	Sandy clay loam soil (% vol)	Moisture content
100% of AWHC	7.3	-	13.9	-
50% of AWHC	3.7	7.9	7.0	24.50
40% of AWHC	2.9	7.2	5.6	23.10
30% of AWHC	2.2	6.5	4.2	21.73
20% of AWHC	1.5	5.7	2.8	20.34

FC = 11.5% vol. and PWP = 4.2% vol. for the loamy sand soil; FC = 31.44% vol, PWP = 17.54% vol. for sandy clay loam soil.

Table 3: Physiological traits of cassava at different levels of irrigation.

Treatment	Photosynthesis rate (μmole $CO_2/m^2/s$)	Stomatal conductance (mole $CO_2/m^2/s$)	Leaf water potential (bar)	Chlorophyll activity
Loamy sand				
50% of AWHC	5.14 a[1]	0.080 a	-3.33 a	0.791 a
40% of AWHC	3.58 b	0.078 ab	-3.40 a	0.819 a
30% of AWHC	3.56 b	0.072 ab	-3.73 b	0.807 a
20% of AWHC	2.93 b	0.065 b	-5.00 c	0.777 a
Control	1.00 c	0.050 c	-11.20 d	0.621 b
Sandy clay loam				
50% of AWHC	7.46 a	0.088 a	-4.06 a	0.781 a
40% of AWHC	2.41 b	0.078 a	-4.40 b	0.757 a
30% of AWHC	2.32 b	0.065 b	-5.26 c	0.747 a
20% of AWHC	1.71 c	0.060 bc	-5.20 c	0.738 a
Control	1.00 c	0.050 c	-11.80 d	0.724 b

[1]Data followed by the same letter in each column does not differ significantly ($P < 0.05$) according to Duncan's multiple range tests.

Table 4: Plant height, stem girth, total dry matter and leaf area index of cassava at 120 DAP.

Treatment	Plant height (cm)	Stem girth (mm)	Total dry matter (g/plant)	LAI
Loamy sand				
50% of AWHC	87.25 a[1]	12.0 a	273.3 a	0.58 a
40% of AWHC	81.25 b	11.0 a	263.8 a	0.50 ab
30% of AWHC	81.75 b	11.3 a	256.5 a	0.45 b
20% of AWHC	76.00 c	11.8 a	214.4 b	0.42 b
Control	57.80 e	9.1 b	29.2 c	0.05 c
CV%	3.5	5.6	7.5	11.52
Sandy clay loam				
50% of AWHC	66.0 a	10.4 a	185.9 a	0.50 a
40% of AWHC	58.0 b	9.1 b	160.5 ab	0.35 ab
30%of AWHC	59.5 b	9.2 b	137.3 b	0.32 b
20% of AWHC	60.0 b	8.8 bc	132.0 b	0.21 b
Control	44.3 c	8.0 c	23.6 c	0.03 c
CV%	4.1	6.5	6.8	6.5

[1]Data followed by the same letter in each column does not differ significantly ($P < 0.05$) according to Duncan's multiple range tests.

activity were recorded at 50% of AWHC, while the lowest values of those traits were observed at control condition for both soils. Moreover, it was found that all physiological traits responded to soil moisture differently between the two soils. They responded more rapidly in sandy clay loam soil than in loamy sand soil when the soil moisture content was reduced from 50% of AWHC.

Effect of the soil moisture content on plant growth

The measured plant height, stem girth, total dry matter and LAI are listed in Table 4. In both soils, the highest and lowest plant growth was recorded in 50% AWHC and control, respectively. In loamy sand soil, the plant height of 50% AWHC treatment was differed significantly from the other treatments. The difference in stem girth among AWHC of 50, 40, 30 and 20% was not significant, but total dry matter decreased at 20% AWHC treatment. In sandy clay loam soil, there was no difference in the plant height among the 40, 30 and 20% AWHC treatments. The same results were obtained from stem girths, total dry matter and LAI. The plant height, stem girth, total dry matter and LAI in loamy sand soil were higher than those in sandy clay loam soil at the same moisture level.

Amount of water used and water use efficiency for cassava

The amount of water used and water use efficiency (WUE) for cassava in both soils are listed in Table 5. There were significant differences in water used and WUE among the treatments in both soils. The highest amount of water used (99.95 and 92.38 L at loamy sand soil and sandy clay loam soil, respectively) was obtained from 50% of AWHC, followed by 40, 30 and 20% of AWHC and the lowest amount (26.00 L) was at the control in both soils. In loamy sand soil, the highest WUE of 2.73 g/L was recorded at 50% of AWHC, while the lowest WUE was in the control treatment (1.12 g/L). In sandy clay loam soil, the highest WUE (2.01 g/L) was observed at 50% of AWHC and the lowest (0.91 g/L) was in control.

Table 5: Correlation coefficients of total dry matter and physiological traits for cassava in loamy sand soil and sandy clay loam soil.

Physiological traits	SC	LWP	CA	Total dry matter
Loamy sand				
Photosynthesis rate	0.953**	0.900*	0.826*	0.913*
Stomatal conductance		0.954**	0.914*	0.940**
Leaf water potential			0.989**	0.990**
Chlorophyll activity				0.924**
Sandy clay loam				
Photosynthesis rate	0.858*	0.851*	0.925*	0.686
Stomatal conductance		0.947**	0.935**	0.891*
Leaf water potential			0.965**	0.961**
Chlorophyll activity				0.858*

*, **Correlation was significant at the level of 0.05 and 0.01, respectively. SC, Stomatal conductance; LWP, Leaf water potential; CA, Chlorophyll activity.

Table 6: Amount of water used and water use efficiency for cassava.

Treatment	Amount used water (liters/season)	Water use efficiency (g/liter)
Loamy sand		
50% of AWHC	99.95 a	2.73 a
40% of AWHC	97.71 b	2.70 a
30% of AWHC	95.07 c	2.70 a
20% of AWHC	91.85 d	2.33 a
Control	26.00 e	1.12 b
CV%	4.22	7.05
Sandy clay loam		
50% of AWHC	92.38 a	2.01 a
40% of AWHC	87.55 b	1.83 b
30% of AWHC	77.92 c	1.76 b
20% of AWHC	69.77 d	1.89 b
Control	26.00 e	0.91 c
CV%	4.41	7.35

Correlation coefficients and critical soil moisture content for cassava

All physiological traits were generally correlated to each other (Table 6). In both soils, the highest correlation was found between leaf water potential and chlorophyll activity. Dry matter also had positive correlations with all physiological traits, except with photosynthesis rate in sandy clay loam soil. However, the highest correlation was found with leaf water potential in both soils.

The critical point of soil moisture content for cassava was estimated in both soils. As shown in Table 6, the predawn leaf water potential had the highest correlation with the total dry matter (r = 0.990** for loamy sand soil and r = 0.961** for sandy clay loam soil). Therefore, it could be used as an indirect parameter to determine critical soil moisture content. The regression analysis between leaf water potential and soil moisture content was positively correlated in both soils. In loamy sand soil, it showed that the regression line of leaf water potential decreased slightly until reaching the soil moisture content of about 6.1%. Subsequently, there was a rapid decrease in leaf water potential. The critical point of soil moisture content was obtained at the intersection point of the two regression lines, which was 5.4% vol. or equivalent to 15.7% of AWHC (Fig 1). In sandy clay loam soil, however, it was found that leaf water potential decreased slightly until reaching the soil moisture content of about 21.1%, after which there was a rapid decrease in leaf water potential. The critical point was obtained at 22.99% vol. or equivalent to 39.0% of AWHC (Fig 2).

Physiological traits such as photosynthesis rate, stomatal conductance and chlorophyll activity were associated with the soil moisture and growth of cassava. Physiological traits were the highest at the level of 50% AWHC in both soils and they reduced with the reduction of soil moisture level. Cassava is considered a drought tolerant crop capable of enduring dry conditions for long periods. In this experiment the soil moisture content above 40% AWHC had a little effect on the physiological processes and biomass productivity of cassava in both soils. At the initial of water deficit cassava adapted to limited soil moisture by attempting to conserve water through the partial closure of leaf stomata which did not reduce the concentration of carbon dioxide in the leaves resulting in the phothosysthesis synthesis being close to normal level (Udomprasert, 2015). Under serverity

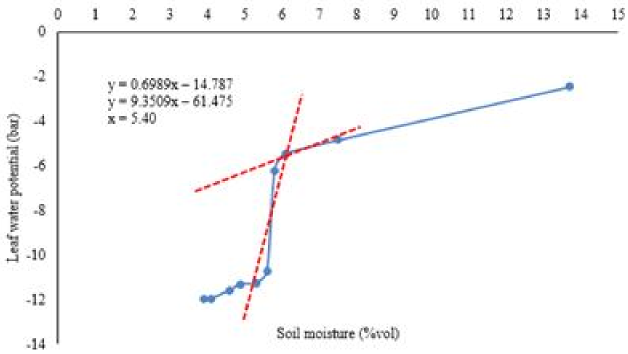

Fig 1: Critical point of water used for cassava in loamy sand soil.

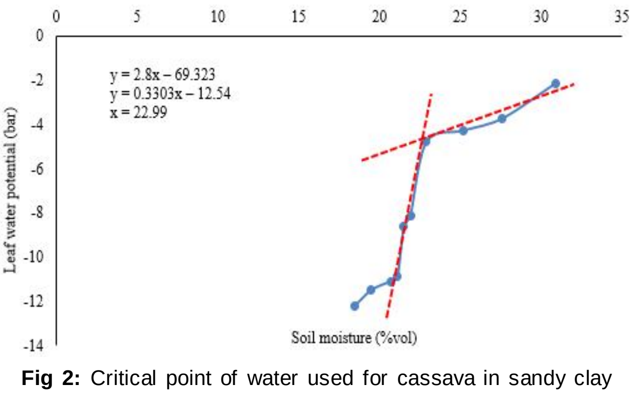

Fig 2: Critical point of water used for cassava in sandy clay loam soil.

of soil moisture content, amount of available water was extremely deficit, which significantly inhibited all physiological traits and biomass production. The results are also in agreement with other researches. The the stomatal conductance and photosynthesis rate declined rapidly as the serverity of water stress increased (Miyashita *et al*., 2005; Upchurch *et al*., 1955) and the chlorophyll activity decreased along with low leaf water potential (Zgallaï *et al*., 2006).

There were different responses to different levels of irrigation between different textured soils. In SCL soil, they were highly responsive to the reduction of soil moisture when the level of irrigation was lower than 40% of AWHC. In LS soil, however, they were not responsive until the level of 20% AWHC. Generally fine texture soils which have more specific surface area can hold water tighter than coarse texture soils which have less specific surface area. Therefore, at the same available soil water content plant roots can uptake soil moisture easier in LS soil than in SCL soil. When irrigation for SCL soil was lower than 40% of AWHC, the roots were unable to absorb enough water to ensure physiological requirement of cassava, while this irrigation level for LS soil was reduced to 20% of AWHC.

Bielorai (1973) and Hsiao (1993) have suggested the method to study critical soil moisture by observing the reduction of water in the soil to the reduction of dry weight of plants. However, the response of dry weight to soil moisture is a complex process and slowly response. Furthermore, data of plant dry matter is able to collect only once, resulting in low accuracy. The physiological characteristics of the plants respond quickly to moisture levels and can be repeatedly measured resulting in high precision data. In this study, predawn leaf water potential which is a physiological trait that can be easily and repeatedly measured, had the highest positive correlation with total dry matter. Therefore, it was used to evaluate the critical point of soil moisture for cassava. Cao *et al*. (2018) also found that leaf water potential was the most sensitive physiological indicator of water deficiency in plant. Sato *et al*. (2006) reported that the predawn leaf water potential positively correlated with soil moisture content and can be as an irrigation timing indicator.

In loamy sand soil, the critical point was at the level of 15.7% of AWHC or equivalent to moisture content of 5.40% vol., while in sandy clay loam soil, it was at the level of 39.0% of AWHC or equivalent to moisture content of 22.99% vol. The different critical points between soil textures related to the water absorbtion ability of soil surfaces ie. LS soil had much lower specific surface area and absobtion ability which allowed roots to uptake more of soil moisture than SCL soil. In this study, when the soil moisture content was controlled above critical points, the growth and total dry matter of cassava were affected to a lesser degree. Futhermore the results also showed that WUE was significantly higher when soil moisture contents were maintained above critical point in both soils. Therefore, the critical soil moisture values in various soil types are very usfull for precision irrigation management in cassava.

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