FERTIGATION FOR CASSAVA PRODUCTION UNDER DRIP IRRIGATION SYSTEM

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มหาวิทยาลัยเทคโนโลยีสุรนารี

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นายซินไท เซีย

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วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาปรัชญาดุษฎีบัณฑิต
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ซินไท เซีย : การให้ปุ๋ยในระบบชลประทานสำหรับการผลิตมันสำปะหลังในระบบน้ำหยด (FERTIGATION FOR CASSAVA PRODUCTION UNDER DRIP IRRIGATION SYSTEM) อาจารย์ที่ปรึกษา : ผู้ช่วยศาสตราจารย์ ดร. สุดชล วุ้นประเสริฐ, 129 หน้า.

ได้ดำเนินการทดลอง 2 การทดลองในสภาพแปลง เพื่อศึกษาผลของการให้น้ำในระบบน้ำหยด และการให้ปุ๋ยระบบชลประทานต่อผลผลิตของมันสำปะหลัง โดยทำการทดลองในฟาร์มมหาวิทยาลัยเทคโนโลยีสุรนารี จังหวัดนครราชสีมา ในการทดลองทั้งสองใช้พันธุ์ห้วยบง 80 ปลูกในดินร่วนเหนียวปนทราย และพันธุ์ระยอง 72 ปลูกในดินทรายร่วน

การทดลองที่ 1 ศึกษาความต้องการน้ำและรูปแบบการใช้น้ำของมันสำปะหลังในระบบน้ำหยด และศึกษาผลของการให้น้ำและการให้ปุ๋ยระบบชลประทานต่อการให้ผลผลิตของมันสำปะหลัง ดำเนินการทดลองช่วง 2558-2559 โดยมีการให้น้ำแบบต่างๆ กัน ได้แก่ T1 : ใช้น้ำฝนและให้ปุ๋ยทางดิน (ควบคุม) T2: ให้น้ำในระบบน้ำหยดและให้ปุ๋ยทางดิน T3 : ให้น้ำในระบบน้ำหยดและให้ปุ๋ยทางระบบชลประทาน ผลการทดลองพบว่าความต้องการน้ำของมันสำปะหลังในดินทั้งสองชนิดเท่ากับ 1,025 มิลลิเมตร เนื่องจากมีการใช้ค่าสัมประสิทธิ์การให้น้ำ (Kc) ในแบบจำลอง ETc ค่าเดียวกัน ปริมาณน้ำที่ให้กับมันสำปะหลังในดินร่วนเหนียวปนทรายเท่ากับ 373 มม. และในดินทรายร่วนเท่ากับ 403 มม. โดยความชื้นในดินของแปลงให้น้ำ T2 (20-31%) มากกว่าแปลงไม่ให้น้ำ T1 (13-23%) สำหรับผลผลิตของมันสำปะหลังที่ได้จากการให้น้ำในระบบน้ำหยด (T2 และ T3) สูงกว่าชุดควบคุม (T1) อย่างมีนัยสำคัญทางสถิติ การให้ปุ๋ยทางระบบชลประทาน (T3) ให้ผลผลิตสูงสุด โดยในดินร่วนเหนียวปนทรายได้ผลผลิต 80.1 ตัน/เฮกตาร์ และดินทรายร่วนได้ผลผลิต 54.6 ตัน/เฮกตาร์ ขณะที่กรรมวิธีการควบคุมมีผลผลิตต่ำสุด โดยในดินร่วนเหนียวปนทรายได้ผลผลิต 42.8 ตัน/เฮกตาร์ และในดินทรายร่วนได้ผลผลิต 29.6 ตัน/เฮกตาร์

การทดลองที่ 2 ศึกษาผลกระทบของความถี่และอัตราการให้ปุ๋ยต่อการผลิตมันสำปะหลังในระบบน้ำหยด ทำการทดลองช่วง 2559-2560 โดยทดสอบเปรียบเทียบวิธีการให้ปุ๋ย 3 วิธี (ให้ปุ๋ยทางดิน ให้ปุ๋ยทางระบบชลประทาน และการให้ปุ๋ยร่วมกันทั้งทางดินและทางระบบชลประทาน) การเปรียบเทียบความถี่ในการให้ปุ๋ยในระบบชลประทาน 2 แบบ (ความถี่น้อยและความถี่มาก) และการเปรียบเทียบปุ๋ย 3 อัตรา (ไม่ให้ปุ๋ย ให้ปุ๋ยตามคำแนะนำของกรมวิชาการเกษตร และให้ปุ๋ยตามหลักการความสมดุลของธาตุอาหาร (Nutrient balance)) ผลการทดลองพบว่าการให้ปุ๋ยในระบบชลประทานช่วยเพิ่มประสิทธิภาพการใช้ปุ๋ย ผลผลิต และปริมาณแป้งของมันสำปะหลังได้อย่างมีนัยสำคัญทางสถิติเมื่อเปรียบเทียบกับการให้ปุ๋ยทางดิน การให้ปุ๋ยตามหลักการความสมดุลของธาตุอาหารมีประสิทธิภาพดีกว่าสูตรปุ๋ยที่ได้จากคำแนะนำการให้ปุ๋ยตามค่าวิเคราะห์ดินของกรมวิชาการเกษตร และการให้ปุ๋ยโดยมีความถี่มากช่วยเพิ่มผลผลิตและรายได้สุทธิได้ดีขึ้นเมื่อเทียบกับการให้

ปุ๋ยแบบความถี่น้อยด้วยปริมาณปุ๋ยเท่ากัน การให้ปุ๋ยทางระบบชลประทานที่มีความถี่มากและใช้สูตรปุ๋ยตามหลักการความสมดุลของธาตุอาหารมีผลทำให้ได้ผลผลิตมันสำปะหลังและรายได้สุทธิสูงที่สุด (90.1 ตัน/เฮกตาร์ และ 144,780 บาท/เฮกตาร์ ในดินร่วนเหนียวปนทราย และ 70.2 ตัน/เฮกตาร์ และ 91,435 บาท/เฮกตาร์ ในดินทรายร่วน) ส่วนรายได้สุทธิและผลผลิตต่ำที่สุดได้จากกรรมวิธีควบคุม ผลการศึกษานี้สรุปได้ว่าการให้ปุ๋ยทางระบบชลประทาน โดยให้มีความถี่มากและใช้สูตรปุ๋ยตามหลักการความสมดุลของธาตุอาหารพืช ช่วยเพิ่มประสิทธิภาพการดูดใช้ธาตุอาหารและประสิทธิภาพการใช้น้ำ เพิ่มผลผลิตและปริมาณแป้งของมันสำปะหลังซึ่งทำให้ได้รายได้สุทธิเพิ่มขึ้น

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สาขาวิชาเทคโนโลยีการผลิตพืช ลายมือชื่อนักศึกษา Lintai Xie

ปีการศึกษา 2561 ลายมือชื่ออาจารย์ที่ปรึกษา

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CASSAVA/WATER REQUIRMENT/DRIP IRRIGATION/FERTIGATION/ FERQUENCY/FERTILIZER RATE

Two field experiments were conducted to study the effects of drip irrigation and fertigation on cassava production at the Suranaree University of Technology Farm, Nakhon Ratchasima, Thailand. In both experiments, Var. HB 80 was grown in sandy clay loam (SCL) soil, and Var. RY 72 was grown in loamy sand (LS) soil.

The first experiment investigated the water requirement and water application pattern of cassava under the drip irrigation system and the effects of irrigation and fertigation on cassava production during the 2015-2016 seasons. The treatments included three different water regimes: T_1: rainfed with soil fertilizer application (control), T_2: drip irrigation with soil fertilizer application, and T_3: drip irrigation with fertigation. The results indicated that the same total water requirement was 1025 mm in both soils because the same Kc was used for the ETc model. The total amount of the supplied water was 373 mm for SCL soil and 403 mm for LS soil. The soil moisture content of the T_2 (20-31%) was more abundant than the T_1 (13-23%). Cassava yield obtained from drip irrigation (T_2 and T_3) was significantly higher than the control (T_1) in both soils. The fertigation treatment produced the highest yield (80.1 ton/ha in SCL soil and 54.6 ton/ha in LS soil), while the control treatment produced the lowest yield (42.8 ton/ha in SCL soil and 29.6 ton/ha in LS soil).

The second experiment investigated the effects of different fertigation frequencies and fertilizer rates on cassava production under the drip irrigation system during the 2016-2017 seasons. The treatments were designed to compare three fertilization methods (soil fertilizer application fertigation and combination of soil fertilizer application and fertigation) two fertigation frequencies (high frequency and low frequency), and three fertilizer rates (no fertilizer, Department of Agriculture (DOA) recommendation, and nutrient balance (NB) model). The results indicated that fertigation significantly increased the water and fertilizer use efficiency, tuber yield and starch content of cassava compared to the soil fertilizer application with the same amount of fertilizer. NB model was significantly better than the DOA recommendation, and high-frequency fertigation significantly enhanced the yield and net income compared to low-frequency fertigation with the same amount of fertilizer. The high-frequency fertigation with the NB model produced the highest tuber yield and net income (90.1 ton/ha and 117,747 B/ha in SCL soil; 70.2 ton/ha and 70,386 B/ha in LS soil) while the lowest tuber yield and net income were produced by the control treatment. The overall results demonstrated that the high-frequency fertigation with the NB model improved the nutrient uptake and water use efficiency, thereby increasing the tuber yield and starch content of cassava, and consequently enhanced the income of farmers.

School of Crop Production Technology	Student's Signature__________
Academic Year 2018	Advisor's Signature__________

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LIST OF ABBREVIATIONS

Av.P	=	Available P
AW	=	Available water
AWHC	=	Available water holding capacity
BD	=	Bulk density
Ca	=	Calcium
CGR	=	Crop growth rate
Cu	=	Copper
CV	=	Coefficient of variation
CWIS	=	Crop water stress index
DAP	=	Days after planting
DI	=	Drip irrigation
DOA	=	Department of Agriculture
EC	=	Electric conductivity
Epan	=	Pan evaporation
ER	=	Effective rain
ET	=	Evapotranspiration
ETc	=	Crop Evapotranspiration
Ex.Ca	=	Exchangeable Ca
Ex.K	=	Exchangeable K
Ex.Mg	=	Exchangeable Mg
FAO	=	Food and Agriculture Organization

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LIST OF ABBREVIATIONS (Continued)

FC	=	Field capacity
Fe	=	Iron
FS	=	Fertilizer supply
FUE	=	Fertilizer use efficiency
GIS	=	Geographic Information System
GPS	=	Global Positioning System
HI	=	Harvest index
K	=	Potassium
Kc	=	Crop coefficient
KUE	=	Potassium use efficiency
LAI	=	Leaf area index
LS	=	Loamy sand
MAP	=	Months after planting
MC	=	Moisture content
Mg	=	Magnesium
N	=	Nitrogen
NB	=	Nutrient balance
NUE	=	Nitrogen use efficiency
OM	=	Organic matter
P	=	Phosphorus
PMC	=	Predicted moisture content
PUE	=	Phosphorus use efficiency

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LIST OF ABBREVIATIONS (Continued)

PWP	=	Permanent wilting point
RCBD	=	Randomized complete block design
RS	=	Remote sensing
S	=	Sulphur
SCL	=	Sandy clay loam
SPSS	=	Statistical Package for the Social Science
TY	=	Tuber yield
WHC	=	Water holding capacity
WS	=	Water supply
WUE	=	Water use efficiency
Zn	=	Zinc

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CHAPTER I

INTRODUCTION

1.1 Rationale and background

Drip irrigation is one of the precision irrigation techniques, which ensures that the soil of central activity area of crop root is always maintained in reasonable water content. To allow crops to absorb the nutrients and water better, agricultural scientists have invented a new technique called fertigation since the middle of the 19th century, which is a perfect combination of fertilization and drip irrigation (Landis et al., 2009). In the fertigation system, water is transported to the root zone by plastic pipes, which can prevent loss of water from leaching and evaporation. Water can be supplied following water requirement of the crop, improving the utilization rate of water. Fertilizers are added to water by an irrigation system, which supplies nutrients timely and moderately for the crop, reducing the waste of fertilizers and preventing soil from hardening. Unlike conventional agriculture fertilization, fertigation can be implemented by the automatic control and reduce time and quantity of labor (Neumann & Snir, 1995). The use of fertigation for crop production is necessary, but it is less implemented in developing countries than in developed countries in the field cultivation (Liang et al., 2014).

The economic crop has vast potential for increasing the income of farmers. Among the economic crops, cassava is an important economic crop for starch (Tonukari, 2004), which is widely grown in tropical areas in the world. Water shortage is a factor that directly limits cassava production in the semiarid area because of low rainfall and its unstable distribution. The moisture content of the soil, which nearly reaches the permanent wilting point after the extended period of drought, will get close to field capacity through drip irrigation. Cassava yield can be significantly increased by drip irrigation (50-80 ton/ha with drip irrigation and 25-35 ton/ha without irrigation), but when the planting areas are all drip-irrigated, high variations in cassava yield can still be presented due to different soil fertility levels and soil fertilization.

The conventional soil fertilization (farmer practice) has some problems on cassava production. Firstly, the fertilizer use efficiency decreases when fertilizers are not dissolved. Fertilizers cannot be dissolved immediately due to water evaporation from soil, and they will be accumulated on the surface of the soil. As time passes, cassava will face growth retardation and reduced yield, with a high rate of nutrient concentration on the surface of the soil. Secondly, conventional soil fertilization causes the uneven distribution of nutrient. Fertilizer is fixed in a certain soil location near the plant. The plant roots cannot move laterally over long distances to absorb nutrient. Final result is the inconsistent growth of crop and the decline in yield and quality (Søgaard and Kierkegaard, 1994). Thirdly, the environmental problem arises with the application of soil fertilizer, as it cannot control the solubility of the fertilizer. Unbalanced nutrient has adverse effect on cassava growth and often results in excessive or inadequate fertilizer for cassava. If the fertilizers are excessive, the extra part of fertilizer will be leached into groundwater, and if the fertilizers are inadequate, cassava will get nutritional disorders (Maynard, 1979).

In order to enhance the yield and quality of cassava, and compensate for the disadvantages of conventional soil fertilization, fertigation would be the best choice to cultivate cassava. Román-Paoli and Sotomayor-Ramírez (2002) tested the hypothesis about the reduction in fertilizer by fertigation and suggested that fertigation could be used in planting cassava under semiarid conditions. Jata et al. (2013) concluded that fertigation was efficient for tuber crop production, with the balanced nutrient requirement and increase in the yield and quality of tuber crops. There was a lot of information on cassava fertigation, but less attention had been paid to the frequency of fertilizer formula for cultivating cassava with fertigation. In Thailand, Department of Agriculture (DOA) recommendation and nutrient balance (NB) model are two representative fertilizer formulas. The amount of fertilizer from DOA recommendation is based on the soil test, which is usually recommended under the rainfed conditions. The amount of fertilizer from nutrient balance model is based on crop's nutrient requirement, available soil nutrient, safe margin and nutrient uptake efficiency. The nutrient balance model could be applied in all planting conditions but works the best under controllable conditions where nutrient uptake efficiency can be accurately estimated.

In this study, water requirement and water application pattern were investigated in drip-irrigated cassava under two different fertility soils. Two fertilizer formulas based on DOA recommendation and nutrient balance model were compared to cultivate cassava under drip irrigation system. Different frequencies of fertigation were tested to determine the optimal fertigation frequency.

1.2 Research objectives

The purpose of this study was to enhance the water use efficiency (WUE), fertilizer use efficiency (FUE) and yield of cassava using fertigation in Northeast Thailand where the growth of cassava is affected by low precipitation and uneven rainfall. The specific objectives of this study were as follows:

(1) To investigate water requirement and water application pattern of cassava under drip irrigation system in two different fertility soils.

(2) To evaluate the growth of cassava between fertilizer rates based on DOA recommendation and nutrient balance model.

(3) To compare the nutrient uptake of cassava at different levels of fertigation frequency.

(4) To find the optimal fertigation frequency and fertilizer rate for cassava production in two different fertility soils.

1.3 Benefits of the study

The study provided useful means for examining and estimating the fertigation of cassava in the drip irrigation system. The results of the study should be used as essential information to support nutrient and water management in cassava production. The benefits of study were as follows:

(1) Water balance equation was accurate and useful for irrigation frequency and duration calculation.

(2) Predicted soil moisture provided a database of soil moisture content for future research in the study area.

(3) Drip irrigation system as a vital source of water could produce different levels of fertigation frequency efficiently.

(4) Fertigation as a water and fertilizer application was a technique for improving tuber yield of cassava.

(5) Two formulas of fertilizer calculated from different approaches (DOA

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recommendation and nutrient balance model) were useful for fertilizer management.

1.4 References

Connor, D. J., Cock, J. H., & Parra, G. E. (1981). Response of cassava to water shortage I. growth and yield. **Field Crops Research**. 4: 181-200.

Jata, S. K., Nedunchezhiyan, M., Saho, T. R., & Sahoo, V. (2013). Fertigation in high value tuber crops–a review. **Odisha Review**. 68-77.

Landis, T. D., Pinto, J. R., & Davis, A. S. (2009). Fertigation-injecting soluble fertilizers into the irrigation system. **Forest Nursery Notes**. 29(2): 4-13.

Liang, X., Gao, Y., Zhang, X., Tian, Y., Zhang, Z., & Gao, L. (2014). Effect of optimal daily fertigation on migration of water and salt in soil, root growth and fruit yield of cucumber (*Cucumis sativus* L.) in solar-greenhouse. **PloS ONE**. 9(1): e86975.

Maynard, D. N. (1979). Nutritional disorders of vegetable crops: a review. **Journal of Plant Nutrition**. 1(1): 1-23.

Neumann, P. M., & Snir, N. (1995). Fertigation: Is there a physiological advantage. **International Water & Irrigation Review**.

Søgaard, H. T., & Kierkegaard, P. (1994). Yield reduction resulting from uneven fertilizer distribution. **Transactions of the ASAE**. 37(6): 1749-1752.

Tonukari, N. J. (2004). Cassava and the future of starch. **Electronic Journal of Biotechnology**. 7(1): 5-8.

Román-Paoli, E., & Sotomayor-Ramírez, D. (2006). New fertigation recommendations for cassava on non-traditional production system. **In 42nd Annual Meeting**, **July 9-15, 2006, Carolina, Puerto Rico (No. 256273). Caribbean Food Crops Society**.

CHAPTER II

LITERATURE REVIEW

2.1 Significant of cassava

Economic crops have several characteristics, such as high economic value, high degree of commercialization, high technology requirements and so on. Cassava (*Manihot esculenta* Crantz), an annual woody perennial shrub crop, is widely grown in tropical areas in the world, which is one of the representative economic crops for starch (Tonukari, 2004). It was native to the tropical zone of Brazil and distributed from the northern Argentina to the southern United States of America, and then it was introduced to Asia in the 16^{th} century. It is the third important crop after rice and corn in Southeast Asia and can produce large amounts of starch from tuber. The main economic crops are aromatic rice, maize and cassava in Thailand (Kuneepong et al., 2001). The cultivation of cassava in Thailand is mainly distributed in the northeastern region (Nakhon Ratchasima, Chaiyaphum and Khon Kaen), the northern region (Kamphaeng Phet and Nakhon Sawan) and the central region (Kanchanaburi) (Amarasinghe et al., 2011). Cassava is more tolerant to drought and high temperature. It was reported that the optimal range of the broad photosynthetic temperature for cassava growth was 25°C to 40°C for leaves (Brown *et al*., 2016). Botanically, the height of cassava can grow from 1.5 m to 5 m, and the shape of tuberous root is long and tapered, rough and brown on the outside, and smooth and cream-white on the inside. Cassava is considered as a major staple food in Africa, its leaves are eaten as a vegetable and tubers can be processed into different foods, while the varieties of cassava are classified as edible with high starch and inedible with chronic cyanide toxicity in Thailand. Bounthanh et al. (2002) reviewed 10 varieties of cassava in Thailand, for eating (Hanatee, Rayong 2, Local red, and Local white) and for starch or animal feed (Rayong 1, Rayong 5, Rayong 60, Rayong 72, Rayong 90, and Kasetart 50). The roles of cassava are such as ethanol fuel (Nguyen and Gheewala, 2008), animal feed (Wanapat, 2002) and extraction of starch (Sriroth et al., 2000). In contrast with tuber, leaves can be harvested for animal feed. Stems are used for planting materials or firewood. The cultivation of cassava is mainly based on the stem cutting. The stems of cassava can be saved as the planting materials for next planting. The planting spacing can be 0.8 × 0.8 m, 1.0 × 1.0 m, 1.2 × 1.2m and 1.5 × 1.5 m (Streck et al., 2014). Silva et al. (2013) reported that the Vermelhinha cultivar of cassava was planted by using the optimal density (13,594 plants/ha) in Brazil, and the yield was more than double that of the farmers.

The average tuber yields are often 10-15 tonnes per ha, and modern varieties grown under good management can yield more than 50 tonnes per ha (Roy, 2006). Different varieties of cassava can contribute different yields. Cock (1976) found two highest yielding varieties, M Colombia 113 (66 tonnes/ha) and M Colombia 22 (32 tonnes/ha) from 40 different varieties of cassava. The related data showed that the yield of cassava in Thailand was 20 t/ha, but the potential yield was 60 t/ha. There are several recommended varieties of cassava in Thailand, which are used for animal feed and starch. Insects are subjected to seasonal increase in Thailand, the population of which begins to increase since the last month of rainy season, and this increasing tendency continues through the cool and dry season (Nair, 2007). Research had shown that the lower the population level of insects is, the more crops would be yielded. In recent years, outbreaks of cassava mealybug (Phenococcus manihoti) caused serious effects on the yield of cassava in Thailand (Burns et al., 2010). To a certain extent, the drought condition also affects the yield of cassava, despite cassava's strong ability of drought tolerance. However, when suffering long-term water shortage, the roots of cassava development will be affected (Sriroth et al., 2001). Soil texture can affect the yield of cassava by water holding capacity. The majority of soil texture in the northeast of Thailand is sandy soil with low water holding capacity (Chanthai et al., 2012). Nutrient applied for cassava will be leaching when the amount of water is applied higher than water holding capacity.

In addition to insect, drought condition, and soil texture, some other factor can also affect the yield of cassava in Thailand such as soil nutrient. The total world yield of the cassava in 2011, 2012 and 2013 are 261 million tons, 269 million tons and 276 million tons, respectively (FAO, 2013). Lots of cassava cultivation brings up the risk of soil nutrient depletion. Soil nutrient losses influence not only the nutrient absorption of cassava but also damage the soil. Cassava can absorb an enormous amount of nutrient from soil and bring about degradation to the soil properties, resulting in infertile soil and soil erosion. Imbalanced nutrient in the soil will reduce the yield of cassava. Therefore, maintaining healthy soil is of paramount importance to enhance nutrient uptake of cassava. Controlling the nutrient balance between cassava and soil is a crucial link to increase the yield of cassava.

2.2 Agricultural technology

The food shortage along with population increase is a world problem. To solve this problem for human, agricultural scientists develop new agricultural technologies for increasing the yield and productivity of the crop. Decades ago, farmers had to cross the field many times when they applied water and fertilizers to crop through traditional agriculture, but now new agricultural technologies are added into modern farms that make a significant change in crop production. The fertilizer and water will be applied to crop together by opening valve only one time at the edge of the field. In addition, more and more benefits are discovered from the advanced devices in agriculture. Holcomb et al. (1992) found that ebb and flow irrigation reduced about 40% water and fertilizer use in the production of Hedera helix compared with overhead hand watering by a hose. Maximum irrigation efficiency and economic return were obtained with sprinkler irrigation in onion production (Al-Jamal, 2001). Fertigation incorporated with biochar could enhance the yield of pepper and increase the plant growth and productivity (Graber et al., 2010). New technologies have produced an ongoing revolution of agriculture in crop production.

Today the technology is not only new but also focuses on the precision in agriculture, such as sensor technology, GPS technology, and robot technology. Precision agriculture targets at the application of fertilizer and water precisely where and when the crop needs (Bongiovanni & Lowenberg, 2004). It has many benefits such as low input, high efficiency, and sustainability (Shibusawa, 1998). The computer is an essential part of precision agriculture, and it is used with sensors to measure climate, soil, water, crop and so on. Wireless sensor networks were used for monitoring microclimates in the crop field (Baggio, 2005). The wireless sensor networks can have different nodes, which can connect to different sensors. In one experiment farmers could measure many different factors such as irrigation water, fertilizer requirement and crop harvesting (Riquelme et al., 2009). Farming also can be carried out with Global Positioning System (GPS) based on the satellite. GPS manage the spatial and temporal variation in the field in almost all developing countries. GPS receivers received the information about the position, time and direction of the crop, soil and water in some specific locations (Shanwad, 2002). Farmers have obtained many benefits from precision agriculture, but challenges and room for innovation in agriculture still exist for farmers.

The product should be safe for consumers and ecosystems. Using agriculture technology to protect the environment and health of human is a green revolution, and ensures the sustainable agricultural development. The infertile soils were formed from loss of soil fertility by erosion, acidification, salinization, and desertification that were problems for sustainable agriculture development (Welch & Graham, 1999). Soil erosion can cause a considerable loss of agriculture, which should be predicted before planting. Remote sensing (RS) and Geographic Information System (GIS) technologies were used to predict and prevent the risk of erosion by the erosion risk mapping in watershed areas (Yuksel et al., 2008). These technologies have an effect to monitor and prevent soil erosion from occurring. Same with RS and GIS technology, drip fertigation also has an excellent effect on salinity soil. GUO et al. (2009) found that drip fertigation could decrease salt accumulation rate in the surface soil and reduce the nitrogen and phosphorus loss in the greenhouse. More and more agriculture technologies are invented and bring benefit to mankind. The computer also can control fertigation to ensure an accurate time for irrigation and save the costs of labors. In the future, farms will become more like factories and mechanization, automation and intelligentization technologies of agriculture will help mankind to solve food shortage problem.

2.3 Drip irrigation

Drip irrigation as an irrigation method provides continuous or intermittent water supply to crops. In drip irrigation system, water is pumped from the water source, transports through plastic pipes and filters, finally enters drip tapes and is practically injected by emitters. The design of the system prevents moisture loss due to evaporation or surface runoff. Drip valves were able to control the flow rate, and irrigation water is slowly dripped around the rhizosphere soil of the crop. Water use efficiency (WUE) can be significantly improved with the optimal irrigation rate. Salah and Mohamed (2008) reported that the highest IWUE of corn was at 1.00 of the estimated evapotranspiration (ET) equivalent to 5955 m^3/ha compared to 0.8 and 0.6 ET. Quezada et al. (2011) found that the highest WUE of carrot was in the 75% pan evaporation (Epan) equivalent to 3864 m^3/ha compared to 100 and 125% Epan. Fertilizer also can be added into the drip irrigation system called the fertigation, which will be talked in section 2.5. Drip irrigation is able to increase water distribution and decrease water. Kumar and Palanisami (2010) summarized that drip irrigation had a significant impact on water resources saving and advocated that the policy should focus on promoting drip irrigation in those regions where water is scarcity.

Drip irrigation is one of the practical irrigation methods for increasing the yield of crop. Researchers have conducted various drip irrigation experiments on various crops such as tomato, cabbage, cassava, sugarcane, corn and so on. Hanson and May

(2003) reported that tomato yield was significantly better in the field experiment with the drip irrigation than with sprinkler irrigation. Tiwari et al. (2003) reported that drip irrigation (DI) treatment produced 62.44% higher yield of cabbage compared to furrow irrigation, and more detail of the study revealed that yield of 111.72 ton/ha obtained from drip irrigation with plastic mulch was higher than DI of 106.68 ton/ha. Amanullah et al. (2006) concluded that higher yield of cassava could be obtained by drip irrigation with once in two days at 75 per cent of surface irrigation in moderate water scarcity areas, and drip irrigation at 50 per cent of surface irrigation compared to conventional surface irrigation also produced better yield and saved about 50 per cent water. The yield of sugarcane used in drip irrigation was increased from 20% to 40%, and irrigation water was saved from 30% to 60% in Maharashtra, India. Lamm and Trooien (2003) reviewed that subsurface drip irrigation with nitrogen fertigation obtained the maximize grain yield of corn in Kansas, USA.

Irrigation scheduling is the process of water application with the correct frequency and duration of watering, and it can base on different irrigation calculations. Kashyap and Panda (2003) used the irrigation scheduling based on maximum allowable depletion of available soil water and stated that tuber yield of potato under high-frequency irrigation was significantly higher than low-frequency irrigation. Alderfasi and Nielsen (2001) concluded that crop water stress index (CWSI) could be used for irrigation scheduling of wheat or other similar crops. Snyder et al. (1987) reported that evapotranspiration (ETc) was calculated by the crop coefficient (Kc) using for the irrigation scheduling in trees and vines. Irrigation frequency affected growth and development of tuber crops such as cassava, potato and sweet potato (Santosa et al., 2004).

2.4 Fertilizer application

Fertilizer is the substance of nutrient that is applied to the soil to supply nutrient for crop growth. The amount of fertilizer application for crop depends on the soil test, crop nutrient requirement and fertilizer use efficiency.

2.4.1 Soil test

Soil test refers to estimate the fertility and health of the soil in order to determine the fertilizer application for the crop in agriculture. Either excess or inadequacy of nutrient in the soil will influence the growth of the crop. The soil test can provide the nutrient information of soil for maintaining the optimal fertility every year, and also can help crops to solve the nutrient problem and help the soil to create a healthy environment. The costs that are spent on fertilizer will be reduced to the minimum. There are many contents in soil test such as pH, EC, N, P and K. Soil pH is the direct mean of expression about acidity and alkalinity of the soil. The growth of crops can be affected by different soil pH. The masses of soil nutrients can be found at 6.0-6.5. The optimum pH range for corn and soybean would be 6.0-6.5 (Pagani, 2011). Soil nutrients will become less available when the levels of soil pH rise, but when the level of pH is dropped, more acid in the soil will cause acid soil toxicity. Acid soil toxicity could affect the growth of different plants through different physiological and biochemical pathway (Foy, 1984). Soil pH not only affects the availability of plant nutrient elements but also affects microorganism. Soil pH affected the bacterial community composition from pH ranges (4.0-8.3) (Rousk et al., 2010). Therefore, it is necessary to measure the soil pH before fertilizer application.

Nitrogen is required by crop with the most significant amount of all essential nutrients. The amount of nitrogen varies significantly in different soils because it loses easily from the soil. Even in the same soil, different years may see the varying amount of nitrogen. Soil nitrogen test is an essential step for nitrogen fertilizer application. Ammonium and nitrate are available forms for crop uptake. The available nitrogen of soil should be known before nitrogen fertilizer application for growing plant. The amount of soil nitrogen had been tested for corn (Magdoff et al., 1984), lettuce (Hartz et al., 2000) and tomato (Krusekopf et al., 2002). Soil phosphorus and potassium test are as essential as nitrogen before fertilizer application. The more nutrient is found in the soil, and the less fertilizer is needed from fertilizer application. Therefore, a soil test can adjust the soil nutrient at the appropriate level.

2.4.2 Crop nutrient requirement

The requirement of nutrient can be determined from soil test. However, different types of crops should meet different nutrient requirements. The total nutrient uptake required in order to produce one tonne of legume crop soybean included 146kg N, 25kg P_2O and 53kg K_2O, but for cereal crop rice, per tonne of production only needed 20kg N, 11kg P_2O and 30kg K_2O (Roy et al., 2006). It could be easily seen from the figures above that soybean consumed N 7 times as much as rice, while P and K only around 2 times. On the other hand, temperature is also a factor that influences the nutrient uptake of plant. The rate of K uptake was the highest at 26-33°C in banana cultivation (Turner & Lahav, 1985). Snapdragons could obtain the maximal growth and nutrient uptake at 22°C root zone temperature (Hood & Mills, 1994). Dong et al. (2001) found that the rate of N uptake increased with soil temperature from 8 to 20°C and changed with plant growth stage in apple plant, N uptake and rate of uptake were influenced by both soil temperature and plant growth stage. Temperature can affect the chemical reactions of nutrient elements in the soil, which will influence nutrient uptake. Plant absorbs nutrients from soil for nutrient requirement. Different plant growth stages require different amount of nutrient. The amount of nutrient requirement will increase with the growth of plant. The growth stages of corn can be divided into leaf, tassel, silk and kernel (Jones et al., 2011). It absorbed N slowly in the early grow stages, but the uptake rate of N would increase rapidly to a maximum which exceed 4kg per ha per day before and after tassel (Roy et al., 2006). Deficiency and excess of nutrients both can inhibit the growth of crop and reduce the yield of crop. Yield is a standard for estimating the strategy of fertilizer application. The amount of nutrients required for producing varies in accordance with the yield of crop. Winter wheat would absorb 200kg N, 55kg P_2O, and 252kg K_2O per ha for 6.7 tonnes of grains, however, 4.6 tonnes of grains only needed 128kg N, 46kg P_2O, and 219kg K_2O per ha (Roy et al., 2006). In order to further understanding, more information about crop nutrient requirement is shown in Table 2.1. Therefore, according to the information above, crop nutrient requirement exerts direct effects on fertilizer application. Monitoring and managing nutrient that crop requires is an important factor to ensure an excellent yield potential.

2.4.3 Fertilizer use efficiency

Fertilizer use efficiency is an essential prerequisite for fertilizer application. It depends on the effectiveness of nutrient uptake from the soil and self-property of soil such as pH and texture, but also on the method and frequency of fertilization, the form of fertilizer, and even on the environment. Fertilizer is a kind of mobile nutrient in the soil. N fertilizer is highly mobile, and K is of comparatively lower mobility, but P is highly immobile in the soil. Because of this mobility, the crop can absorb the available forms of the nutrient for crop consumption. The available forms of the nutrient can directly influence fertilizer use efficiency. Less available nutrient in the soil is converted, lower the fertilizer use efficiency will be.

Table 2.1 Crop nutrient requirement for some major field crops (Roy et al., 2006).

Crop categorization		**Nutrient requirement (kg/ha)**			**Yield (t/ha)**	**Area**
		N	**P**	**K**		
Cereals	Wheat	200	55	252	6.7	
		128	46	219	4.6	India
Grain	Rice	20	11	30	1	
	Maize	191	89	235	9.5	Nort
Legumes	Chickpea	91	14	60	1.5	
	Pigeon pea	85	18	75	1.2	
Oil crops	Peanut	192	48	80	3	Ame
	Soybean	146	25	53	1	
	Sunflower	131	87	385	3.5	
Tuber crops	Potatoes	306	93	487	90	UK
		117	32	224	36	India
	Cassava	198	70	220	37	
Sugar	Sugar cane	0.8	0.3	1.32	1	Braz
Fibre	Cotton	156	36	151	2.5	Braz
	Jute	35.2	20.3	63.2	1	India

Crops choose the suitable soil for growing. In a certain sense, soil properties dominate the grown region of the crop. The complex interactions of the biological, chemical and physical properties of soils also influence fertilizer use efficiency (Syers et al., 2008). Soil texture is controlled by the amount of sand, silt, and clay in the soil. Soil texture also influences water and fertilizer in the soil. Different soil textures can lead to different fertilizer use efficiency. Porous soils included sand, loamy sand, and sandy loam, which caused very low N use efficiency in rice cultivation (Aulakh, 1996). Compared with soil texture, soil pH is another important aspect that influences fertilizer use efficiency in soil properties. Soil pH is the most commonly measured property of soil. P use efficiency was higher than K use efficiency in the soil of pH 6.4 by dry bean (Fageria & Barbosa, 2008). Therefore, the most important relationship between soil property and fertilizer use efficiency is that fertilizer use efficiency changes in accordance with soil properties.

Whether fertilizer should be added or not to the soil that can be decided based on the different methods of fertilization adopted, resulting in different fertilizer applications. In other words, fertilizer use efficiency is affected by different methods. P use efficiency is often up to 90% high when the balance method is used (Syers et al., 2008). Fertilizer use efficiency is also influenced by the frequency of fertilization. Proper fertilizer use frequency can increase fertilizer use efficiency and reduce nutrient loss. The highest N use efficiency of citrus could be achieved by daily irrigation with fertigation every 15 days, compared respectively with fertigation on a daily basis, fertigation every 3 days, and irrigation every 3 days with fertigation every 15 days (Melgar et al., 2010). In terms of fertilizer, the type, and form of fertilizer also decide the fertilizer use efficiency. Ammonium and urea fertilizer are more efficient than nitrate fertilizers in paddy cultivation. Soluble P is more efficient than stable P for short duration crop. Fertilizer is a critical factor of agricultural input that influences the fertilizer use efficiency in crop production. Lower fertilizer use efficiency is due to the losses of nutrients by leaching, gaseous emission and fixation by soil (Baligar et al., 2001). The environment causes some of these problems. Therefore, environmental factors affect the fertilizer use efficiency, naturally.

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2.5 Fertilizer formulas

Fertilizer recommendation refers to the suggestions for fertilization crop consultants give to farmers based on soil test. It is a quantitative fertilization technique. There are different fertilizer recommendations for different soil types. About 20%-50% of the recommended amount of N basal application was suitable for growing rice in Agro Ecological Regions soil in Sri Lanka (Wickramasinghe & Wijewardena, 2000). Fertilizer recommendation has been used for various plants in agriculture, such as N fertilizer for winter wheat (Vaughan et al., 1990), corn (Hanway & Dumenil, 1955) and rice (Saleque et al., 2005). Farmers also can increase or decrease the dosage from fertilizer recommendation in order to bring out the best parameters of plants. A field experiment about the rates of nitrogen fertilizer application of cauliflower was conducted with fertilizer recommendation, and found that N dosage up to 125% of the fertilizer recommendation could obtain larger curds and higher curd yield; N dosage down to 50% of the DOA recommendation could keep the curds stored at room condition for 6 days and 9 days (Kodithuwakku & Kirthisinghe, 2010). Fertilizer recommendation can give farmers accurate guidance in fertilizer application. Experimenters use fertilizer recommendation to determine the range of fertilizer treatments. Therefore, fertilizer recommendation can be a standard to follow in crop production.

Nutrient balance model is a tool of calculation for improving nutrient use efficiency and reducing nutrient loss in agriculture. It provides essential information about the environment and is suitable for both organic and inorganic fertilizers. The nutrient balance includes two factors, one being from inputs, which refers to fertilizers, and the other from outputs referring to the uptake of nutrients. In order to ensure a coordinated development between crop and environment, the balance should be maintained between inputs and outputs. Nutrient balance model provides nutrient based on crop's nutrient requirement, available nutrient in the soil, safe margin and nutrient uptake efficiency. These four elements concerning three factors, i.e., crop, soil, and fertilizer, should be taken into account in order to complete the fertilization and ensure the accuracy of fertilizer application. N fertilizer is lost easily via volatilization, denitrification, and leaching, and it also can be compensated by rainfall and biological fixation (Olson & Kurtz, 1982). The information about nutrient requirements of crops must be needed for nutrient management to improve yield and quality in agriculture. In some crops, excessive application of N fertilizer can increase nitrate, but at the same time can decrease the concentration of Mg and Ca, causing a waste of fertilizer and a potential risk to pollute the environment (Wang et al., 2008). However, as we know, if too less N fertilizer is applied, soil fertility will be reduced, and nutrient deficiency will be presented. Soil available nutrient and safe margin are information concerning soil in nutrient balance model. The amount of available soil nutrient is determined by soil mass and the available value of nutrient which is determined by the soil test, and the safe margin is the amount of available soil nutrient to be reserved in the soil (Papadopoulos et al., 2005). In addition to the nutrient requirement of the crop, the available nutrient in the soil and safe margin, and nutrient uptake efficiency are also essential elements in nutrient balance model, which depends on soil type, environment, irrigation and fertilization methods (Papadopoulos et al., 2005). The amount of nutrient as estimated by nutrient balance model can be reliably applied to the crop, which, as a result, will produce a higher yield than conventional fertilization.

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2.6 Fertigation research

Fertigation is an efficient technique for fertilizer and water management. It is a compound word that comes from fertilizer and irrigation. Only soluble fertilizers can be injected, and thus soluble fertilizers can be injected directly into the irrigation system. Therefore, there are two elements included in the fertigation, namely fertilizer and water.

Fertilizers are the source of nutrient for crops in fertigation. Two forms of fertilizers are suitable for fertigation, i.e., solid and liquid. Fertilizer availability and price are two factors that need to be considered when selecting fertilizers for fertigation. Between the two forms, solid fertilizers are a better choice for fertigation. Solid fertilizers not only have fertilizer availability, but the price is lower than liquid fertilizers. Characteristics of solid fertilizers for fertigation should include high quality, high solubility and purity, low salt level and acceptable pH (Kafkafi & Tarchitzky, 2011). Fertilizer solubility is significant in fertigation. Fertigation tape will be clogged if fertilizers cannot be dissolved in the irrigation water. Solid fertilizers can be dissolved in the optimum water, but when two or more fertilizers are mixed together, the solubility of fertigation will be decreased and still can be increased with a specific temperature (Kafkafi, 2005). Low temperature can cause precipitation of the solid fertilizers in the tank and a lower release rate of solid fertilizers in the water. Three types of fertilizers were tested at the temperatures 5-45°C in the water, the result showed that after 19 weeks, the percentage of fertilizer residue was 66%, 58% and 55% at 20°C, and 36%, 20% and 28% at 45°C in the water, respectively (Lamont et al., 1987). This also proved that different compounds of fertilizers would have different characteristics of solubility. Choosing the optimum fertilizers for fertigation is a vital link.

Compatibility of fertilizers is another essential characteristic of fertilizers. Sometimes fertilizers are likely to precipitate when two or more fertilizers are mixed together. Ben et al. (1974) found that tomato yield could increase by 30% when the N P K fertilizer solution with good compatibility was injected into the trickle line. The reaction product of calcium salt will most likely precipitate, such as calcium phosphate. The pH of fertilizers has a relationship with precipitation in fertigation solution. The optimum range of fertigation pH is 5.5 to 7.0, too high a pH will reduce the availability of P and cause Ca precipitation in the fertigation lines and too low a pH will harm the root of crop and increase Al concentration in the soil solution (Kafkafi, 2005). There are many sources of N such as urea, ammonium nitrate, calcium nitrate and potassium nitrate in fertigation. Sometimes ammonium fertilizers can produce precipitation to block the fertigation emitters. Urea, Ammonium phosphate and Potassium chloride are primary sources of NPK for field crops of fertigation.

Fertigation was invented to tackle the problem of water shortage in desert area and spread rapidly all over the world. There are two aspects for the quick expansion of fertigation. One is that with fertigation farmers can irrigate huge field areas easily, the other being that the worldwide shortage of irrigation water can be solved (Kafkafi, 2005). Water is injected into fertigation lines by injection pump. Fertigation lines can give water a suitable flow environment and also prevent water evaporation. Sometimes lines will be clogged if water quality is not good, so the quality of fertigation water is as important as the choice of fertilizer. Clogging will damage the uniformity of water distribution, which is the biggest problem in fertigation system. The main reason for clogging is the mixed substances such as chemical ions in the water. Sewage water is recycled for irrigation in some arid and semi-arid zones. Sewage water contains more

N, P and K than fresh water, so lines or emitters are more easily clogged. For clogging problem, LI et al. (2012) found that chlorination of sewage water could solve the problem of emitter clogging effectively. Drip fertigation is method of fertigation for field corps. The quality and source of water directly influence the efficiency of drip fertigation. In this case, water filtration can prevent clogging of drip lines and emitters in drip fertigation, and can maintain the uniformity of water distribution (Kafkafi, 2005). Filtration system can prevent gravel and sand from entering the water in the drip fertigation lines. Currently, the surface and subsurface water are the main water sources of fertigation in agriculture. In the future, the development of fertigation will increasingly rely on water sources from the groundwater, sewage water, or even seawater.

Fertigation is more effective than conventional practice with fertilization and irrigation conducted separately. It applies water movement in the lines of fertigation under the plastic mulch, and at the same time avoids water movement above the soil surface, thereby water loss from evaporation is reduced to a minimum. In conventional soil fertilization, water will undoubtedly be lost from evaporation, especially in semiarid and arid zones where there is low water holding capacities. A reduction in the total biomass of cassava was caused by water shortage in both stems and roots (Connor et al., 1981). The yield and quality of fertigation vegetables such as muskmelons, honeydews, watermelons, cucumbers, tomatoes, peppers and sweet corns had shown a significant increase with plastic mulches (Lamont, 2017). Fertigation can modify the humidity of soil environment and enables accurate water application to the individual crop. Zotarelli et al. (2008) evaluated the placements of drip and fertigation lines at 3 different depths (SUR: both irrigation and fertigation drip lines placed on the surface;

S&S: both lines buried 0.15 m deep; SDI: irrigation line placed 0.15 m below the fertigation line on the surface) on the growth and fruit yield of Zucchini squash and found that SDI increased yield and water use efficiency by 16% and 75%, respectively. Fertigation also can irrigate the rough areas such as hilly area. It uses the optimum amount of water to produce the highest yield in agriculture. Higashide et al. (2007) used fertigation system to produce tomato in summer and autumn seasons in hilly and mountain areas steadily. These advantages of fertigation, concerning water, can be applied in a wide range of contexts, from small gardens to huge plantations.

The frequency of fertigation often is recommended in drip fertigation. Gaur and Kumar (2003) used different doses of nitrogen fertilizer to evaluate the performance of drip fertigation system and found that frequent applications of N (30g N/plant) gave best fertilizer application efficiency, but it considerably reduces the water application uniformity because of higher clogging of emitters in lemon plants. However, both high and low frequency of fertigation can influence growth, yield and water uptake and nutrient of the crop. High fertilizer frequency could see a significant increase in yield as a result of enhancement of nutrient uptake, but low fertilizer frequency saw a reduction of yield due to nutrient deficiency in lettuce production (Silber et al., 2003). Willis et al. (1990) also found that Low N concentrations with the frequent application could minimize residual N in the soil. The concentrations of fertilizer are reduced in soil by frequent fertigation. High frequency is often advocated in fertigation literature because the moisture and nutrient of soil can be maintained at a constant level in the root zone (Farneselli et al., 2015). Sometimes to select a high or low frequency of fertigation depends on the type of soil. For example, too frequent fertigation is not necessary for clay soil, because the soil particles of clay stick together and have a high water holding capacity. Lahav and Kalmar (1988) found that continuous fertilization could not affect the yield of banana in clay soil. The broccoli yield produced from fertigation on a daily or weekly basis is higher than that from the low frequent fertigation, with the weekly fertigation still overweighing the daily practice (Thompson et al., 1999). Moreover, due to constant evaporation of water from the frequent fertigation, water waste is increased in amount (Simonne et al., 2004).

Fertigation gives the cassava the amounts of fertilizers during the growth cycle and ensures the correct doses of fertilizers in different growth stages. There are several advantages for cassava, such as accurate and uniform fertilization, the appropriate concentration of the nutrient, active uptake of nutrients, and lower nutrient loss and production costs. Hence a high yield, an excellent quality product with less time and labor. There are many reports on the application of drip irrigation on crops such as potato tomato corn lettuce strawberry grape etc. while few researches focus on cassava drip irrigation.

2.7 References

Alderfasi, A. A., & Nielsen, D. C. (2001). Use of crop water stress index for monitoring water status and scheduling irrigation in wheat. **Agricultural Water Management**. 47(1): 69-75.

Al-Jamal, M. S., Ball, S., & Sammis, T. W. (2001). Comparison of sprinkler, trickle and furrow irrigation efficiencies for onion production. **Agricultural Water Management**. 46(3): 253-266.

Amanullah, M. M., Mohamed Yassin, M., Vaiyapuri, K., Somasundaram, E., Sathyamoorthi, K., & Padmanathan, P. K. (2006). Growth and yield of cassava

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as influenced by drip irrigation and organic manures. **Research Journal of Agriculture and Biological Sciences**. 2(6): 554-558.

Amarasinghe, U. A., Damen, B., Eriyagama, N., Soda, W., & Smakhtin, V. (2011). **Impacts of rising biofuel demand on local water resources: case studies in Thailand and Malaysia**. Report of the IWMI-FAO Bioenergy in Asia and the Pacific Project.

Aulakh, M. S. (1996). Nitrogen losses and fertilizer N use efficiency in irrigated porous soils. **Nutrient Cycling in Agroecosystems**. 47(3): 197-212.

Baggio, A. (2005, June). Wireless sensor networks in precision agriculture. In **ACM Workshop on Real-World Wireless Sensor Networks (REALWSN 2005)**. (pp 1567-1576). Stockholm, Sweden.

Baligar, V. C., Fageria, N. K., & He, Z. L. (2001). Nutrient use efficiency in plants. **Communications in Soil Science and Plant Analysis**. 32(7-8): 921-950.

Ben Asher, J., Yosef, B. B., & Kafkafi, U. (1974). Application of an irrigation model and fertilization considerations in growing tomato on a sand dune. **Plant analysis and fertilizer problems**. Proc. 7th IPNC, Hanover, Germany, 1.

Bongiovanni, R., & Lowenberg-DeBoer, J. (2004). Precision agriculture and sustainability. **Precision Agriculture**. 5(4): 359-387.

Bounthanh, K., Reinhardt, H., Peter, H., Peter, K., & Bruce, L. (2002). Cassava variety evaluation. **Integrated Farming Systems Research**. 168-171.

Brown, A. L., Cavagnaro, T. R., Gleadow, R., & Miller, R. E. (2016). Interactive effects of temperature and drought on cassava growth and toxicity: implications for food security?. **Global Change Biology**. 22(10): 3461-3473.

Burns, A., Gleadow, R., Cliff, J., Zacarias, A., & Cavagnaro, T. (2010). Cassava: the drought, war and famine crop in a changing world. **Sustainability**. 2(11): 3572-3607.

Chanthai, S., Machikowa, T., Wonprasaid, S., & Boonkerd, N. (2012). Effects of fertigation, water application frequency and soil amendment on tomato production. In **VII International Symposium on Mineral Nutrition of Fruit Crops 984**. (pp 187-195).

Cock, J. H. (1976). Characteristics of high yielding cassava varieties. **Experimental Agriculture**. 12(2): 135-143.

Dong, S., Scagel, C. F., Cheng, L., Fuchigami, L. H., & Rygiewicz, P. T. (2001). Soil temperature and plant growth stage influence nitrogen uptake and amino acid concentration of apple during early spring growth. **Tree Physiology**. 21(8): 541-547.

Fageria, N. K., & Barbosa Filho, M. P. (2008). Influence of pH on Productivity, Nutrient Use Efficiency by Dry Bean, and Soil Phosphorus Availability in a No-Tillage System. **Communications in Soil Science and Plant Analysis**. 39(7-8): 1016-1025.

FAO (Food and Agriculture Organization), 2013. http://faostat3.fao.org/.

Foy, C. D. (1984). Physiological effects of hydrogen, aluminum, and manganese toxicities in acid soil. **Soil Acidity and Liming**. 57-97.

Franco, J. G., King, S. R., Masabni, J. G., & Volder, A. (2015). Crop functional diversity improves short-term yields in a low-input intercropping system. **Agriculture, Ecosystems & Environment**. 203: 1-10.

Gaur, M. L., & Kumar, A. (2003). Performance evaluation of drip fertigation system in lemon plants. **Indian Journal of Soil Conservation**. India.

Guo, C. X., Shen, G. X., Huang, L. H., Qian, X. Y., Xu, X. H., & Massimo, P. (2009). Control of soil salinization and reduction of N & P loss with drip fertigation in greenhouse. **Journal of Agro-Environment Science**. 28(2): 287-191.

Hanson, B., & May, D. (2003). Drip irrigation increases tomato yields in salt-affected soil of San Joaquin Valley. **California Agriculture**. 57(4): 132-137.

Hanway, J., & Dumenil, L. (1955). Predicting nitrogen fertilizer needs of Iowa soils: III. Use of nitrate production together with other information as a basis for making nitrogen fertilizer recommendation for corn in Iowa. **Soil Science Society of America Journal**. 19(1): 77-80.

Hartz, T. K., Bendixen, W. E., & Wierdsma, L. (2000). The value of presidedress soil nitrate testing as a nitrogen management tool in irrigated vegetable production. **Hort Science**. 35(4): 651-656.

Higashide, T., Ibuki, T., Kasahara, Y., Sumikawa, O., Sakoda, T., & Kinoshita, T. (2007). Cultivation of tomato [Lycopersicon esculentum] in a sloped greenhouse by a fertigation system suitable for use on sloping land. **Horticultural Research**. Japan.

Holcomb, E. J., Gamez, S., Beattie, D., & Elliott, G. C. (1992). Efficiency of fertigation programs for Baltic Ivy and Asiatic Lily. **Hort Technology**. 2(1): 43-46.

Hood, T. M., & Mills, H. A. (1994). Root zone temperature affects nutrient uptake and growth of snapdragon. **Journal of Plant Nutrition**. 17(2-3): 279-291.

Jones, C., Olson-Rutz, K., & Dinkins, C. P. (2011). **Nutrient uptake timing by crops**. Montana, USA, Montana State University.

Kafkafi, U. (2005). Global aspects of fertigation usage. In **Fertigation Proceedings, International Symposium on Fertigation**. (pp 8-22). Beijing, China.

Kafkafi, U., & Tarchitzky, J. (2011). **A tool for efficient fertilizer and water management**. Paris, France.

Kashyap, P. S., & Panda, R. K. (2003). Effect of irrigation scheduling on potato crop parameters under water stressed conditions. **Agricultural Water Management**. 59(1): 49-66.

Kodithuwakku, D. P., & Kirthisinghe, J. P. (2010). The effect of different rates of nitrogen fertilizer application on the growth, yield and postharvest life of cauliflower. **Tropical Agricultural Research**. 21(1): 110-114.

Krusekopf, H. H., Mitchell, J. P., Hartz, T. K., May, D. M., Miyao, E. M., & Cahn, M. D. (2002). Pre-sidedress soil nitrate testing identifies processing tomato fields not requiring sidedress N fertilizer. **Hort Science**. 37(3): 520-524.

Kumar, D. S., & Palanisami, K. (2010). Impact of drip irrigation on farming system: Evidence from southern India. **Agricultural Economics Research Review**. 23:265-272.

Kuneepong, P., Kongton, S., Wangwachrakul, V., & Sumdin, S. (2001). Modelling economic crop yield and climate change in Thailand. In **ModSim 1. International Congress on Modelling and Simulation**. (pp 10-13).

Lahav, E., & Kalmar, D. (1988). Response of banana to drip irrigation, water amounts and fertilization regimes. **Communications in Soil Science & Plant Analysis**. 19(1): 25-46.

Lamm, F. R., & Trooien, T. P. (2003). Subsurface drip irrigation for corn production: a review of 10 years of research in Kansas. **Irrigation Science**. 22(3-4): 195-200.

Lamont, W. J. (2017). Plastic mulches for the production of vegetable crops. **A Guide to the Manufacture, Performance, and Potential of Plastics in Agriculture**. 45-60.

Lamont, G. P., Worrall, R. J., & O'Connell, M. A. (1987). The effects of temperature and time on the solubility of resin-coated controlled-release fertilizers under laboratory and field conditions. **Scientia Horticulturae**. 32(3-4): 265-273.

LI, J. S., LI, Y. F., & ZHANG, H. (2012). Tomato yield and quality and emitter clogging as affected by chlorination schemes of drip irrigation systems applying sewage effluent. **Journal of Integrative Agriculture**. 11(10): 1744-1754.

Magdoff, F. R., Ross, D., & Amadon, J. (1984). A soil test for nitrogen availability to corn. **Soil Science Society of America Journal**. 48(6): 1301-1304.

Melgar, J. C., Schumann, A. W., & Syvertsen, J. P. (2010). Fertigation frequency affects growth and water and nitrogen use efficiencies of swingle citrumelo citrus rootstock seedlings. **Hort Science**. 45(8): 1255-1259.

Nair, K. S. (2007). **Tropical forest insect pests: ecology, impact, and management**. Cambridge University.

Nguyen, T. L. T., & Gheewala, S. H. (2008). Life cycle assessment of fuel ethanol from cassava in Thailand. **The International Journal of Life Cycle Assessment**. 13(2): 147-154.

Olson, R., & Kurtz, L. T. (1982). Crop nitrogen requirements, utilization, and fertilization. **Nitrogen in Agricultural Soils**. 567-604.

Pagani, A. (2011). **Soil pH and lime management for corn and soybean**. Iowa State University.

Papadopoulos, I., Metochis, C., & Seraphides, N. (2005). **Fertigation recipes for selected crops in the Mediterranian region**. Agricultural Research Institute.

Quezada, C., Fischer, S., Campos, J., & Ardiles, D. (2011). Water requirements and water use efficiency of carrot under drip irrigation in a haploxerand soil. **Journal of soil science and plant nutrition**. 11(1): 16-28.

Riquelme, J. L., Soto, F., Suardíaz, J., Sánchez, P., Iborra, A., & Vera, J. A. (2009). Wireless sensor networks for precision horticulture in Southern Spain. **Computers and Electronics in Agriculture**. 68(1): 25-35.

Rousk, J., Bååth, E., Brookes, P. C., Lauber, C. L., Lozupone, C., Caporaso, J. G., ... & Fierer, N. (2010). Soil bacterial and fungal communities across a pH gradient in an arable soil. **The ISME Journal**. 4(10): 1340.

Roy, R. N., Finck, A., Blair, G. J., & Tandon, H. L. S. (2006). Nutrient management guidelines for some major field crops. **Plant Nutrition for Food Security**. A Guide for Integrated Nutrient Management. FAO, Rome, 235-349.

Salah, E., & Mohamed, A. I. (2008). **Effective water management of drip irrigation to improve water use efficiency and yield of corn under Egyptian conditions**.

Saleque, M. A., Naher, U. A., Choudhury, N. N., & Hossain, A. T. M. S. (2005). Variety-specific nitrogen fertilizer recommendation for lowland rice. **Communications in Soil Science and Plant Analysis**. 35(13-14): 1891-1903.

Santosa, E., Sugiyama, N., Sulistyono, E., & Sopandie, D. (2004). Effects of watering frequency on the growth of elephant foot yams. Japanese **Journal of Tropical Agriculture**. 48(4): 235-239.

มหาวิทยาลัยเทคโนโลยีสุรนารี

Shanwad, U. K., Patil, V. C., Dasog, G. S., Mansur, C. P., & Shashidhar, K. C. (2002, October). Global positioning system (GPS) in precision agriculture. In **The Asian GPS Conference**. : 24-25.

Shibusawa, S. (1998, October). Precision farming and terra-mechanics. In **The fifth ISTVS Asia-Pacific regional conference** in Korea. : 20-22.

Silber, A., Xu, G., Levkovitch, I., Soriano, S., Bilu, A., & Wallach, R. (2003). High fertigation frequency: the effects on uptake of nutrients, water and plant growth. **Plant and Soil**. 253(2): 467-477.

Simonne, E. H. D. W., Studstill, D., & Hochmuth, R. C. (2004). Understanding water movement in mulched beds on sandy soils: An approach to ecologically sound fertigation in vegetable production. In **International Symposium Towards Ecologically Sound Fertilisation Strategies for Field Vegetable Production 700**. : 173-178. International Society for Horticultural Science.

Silva, T. S., Braga, J. D., Silveira, L. M. D., & Sousa, R. P. D. (2013). Planting density and yield of cassava roots. **Revista Ciência Agronômica**. 44(2): 317-324.

Snyder, R. L., Lanini, B. J., Shaw, D. A., & Pruitt, W. O. (1987). **Using reference evapotranspiration (ETo) and crop coefficients to estimate crop evapotranspiration (ETc) for trees and vines**. Leaflet-University of California.

Sriroth, K., Piyachomkwan, K., Santisopasri, V., & Oates, C. G. (2001). Environmental conditions during root development: drought constraint on cassava starch quality. **Euphytica**. 120(1): 95-102.

Sriroth, K., Piyachomkwan, K., Wanlapatit, S., & Oates, C. G. (2000). Cassava starch technology: the Thai experience. **Starch-Stärke**. 52(12): 439-449.

มหาวิทยาลัยเทคโนโลยีสุรนารี

Streck, N. A., Pinheiro, D. G., Junior Zanon, A., Gabriel, L. F., Rocha, T. S. M., Souza, A. T. D., & Silva, M. R. D. (2014). Effect of plant spacing on growth, development and yield of cassava in subtropical environment. **Bragantia**. 73(4): 407-415.

Syers, J. K., Johnston, A. E., & Curtin, D. (2008). Efficiency of soil and fertilizer phosphorus use. **FAO Fertilizer and Plant Nutrition Bulletin**. 18: 1-108.

Thompson, T. L., White, S. A., Walworth, J., & Sower, G. (1999). **Fertigation Frequency Effects on Yield and Quality of Subsurface Drip-Irrigated Broccoli**. University of Arizona College of Agriculture 1999 Vegetable Report.

Tiwari, K. N., Singh, A., & Mal, P. K. (2003). Effect of drip irrigation on yield of cabbage (Brassica oleracea L. var. capitata) under mulch and non-mulch conditions. **Agricultural Water Management**. 58(1): 19-28.

Tonukari, N. J. (2004). Cassava and the future of starch. **Electronic Journal of Biotechnology**. 7(1): 5-8.

Turner, D. W., & Lahav, E. (1985). Temperature influences nutrient absorption and uptake rates of bananas grown in controlled environments. **Scientia Horticulturae**. 26(4): 311-322.

Vaughan, B., Barbarick, K. A., Westfall, D. G., & Chapman, P. L. (1990). Spring nitrogen fertilizer recommendation models for dryland hard red winter wheat. **Agronomy Journal**. 82(3): 565-571.

Wanapat, M. (2002). The role of cassava hay as animal feed. **DOA CIAT**. 504-518.

Wang, Z. H., Li, S. X., & Malhi, S. (2008). Effects of fertilization and other agronomic measures on nutritional quality of crops. **Journal of the Science of Food and Agriculture**. 88(1): 7-23.

มหาวิทยาลัยเทคโนโลยีสุรนารี

Welch, R. M., & Graham, R. D. (1999). A new paradigm for world agriculture: meeting human needs: productive, sustainable, nutritious. **Field Crops Research**. 60(1-2): 1-10.

Wickramasinghe, W. M. A. D. B., & Wijewardena, J. D. H. (2000). Soil and nutrient management for increasing soil fertility towards increased rice productivity in Sri Lanka. **Annals of the Sri Lanka Department of Agriculture**. 2: 465-482.

Willis, L. E., Davies, F. S., & Graetz, D. A. (1990). Fertilization, nitrogen leaching and growth of young 'Hamlin'orange trees on two rootstocks. **Proceedings of the Florida State Horticultural Society**. 103: 30-37.

Yuksel, A., Gundogan, R., & Akay, A. E. (2008). Using the remote sensing and GIS technology for erosion risk mapping of Kartalkaya dam watershed in Kahramanmaras, Turkey. **Sensors**. 8(8): 4851-4865.

Zotarelli, L., Dukes, M. D., Scholberg, J. M., Hanselman, T., Le Femminella, K., & Munoz-Carpena, R. (2008). Nitrogen and water use efficiency of zucchini squash for a plastic mulch bed system on a sandy soil. **Scientia Horticulturae**. 116(1): 8-16.

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CHAPTER III

CASSAVA WATER REQUIREMENT AND EFFECTS OF DRIP IRRIGATION AND FERTIGATION ON CASSAVA PRODUCTION IN TWO DIFFERENT TEXTURED SOILS

3.1 Abstract

This chapter investigated the water requirement and water application pattern of cassava under the drip irrigation system and the effects of drip irrigation and fertigation on cassava production during the 2015-2016 seasons. The experiments were conducted in two textured soils (sandy clay loam (SCL) and loamy sand (LS)). The ETc model and the water balance equation were used to determine the amount of irrigation water. Treatments of the study included three different water regimes: T_1: rainfed with soil fertilizer application (control) T_2: drip irrigation with soil fertilizer application and T_3: drip irrigation with fertigation. The temporal variation of SCL soil moisture content at the 0-30 cm depth was monitored during the 2^{nd} and 4^{th} month in the control plot (T_1) and irrigated plot (T_2). The results indicated that the total amount of supplied water was 373 mm for SCL soil and 403 mm for LS soil. The soil moisture content of T_2 gradually decreased to 20-21% before irrigation, but after the irrigation, it returned to 29-31%, closed to the field capacity (FC) (31%). While in T_1, the soil moisture content gradually decreased and remained relatively constant at about 14-17%, closed to the permanent wilting point (PWP) (14.5%) until there was rain which brought it back to the FC again. There was a significant relationship (R^2 = 0.8)

between the measured moisture content and the predicted moisture content which was calculated from the ETc model and water balance equation.

In both soils, the highest and the lowest plant height of cassava were observed from T_3 and T_1, respectively. The leaf nutrient contents including N K Ca Mg and S in T_3 were the highest in both soils, while they were the lowest in T_1. However, the difference of P content among treatments was not significant in both soils. The tuber yield of cassava obtained from drip irrigation treatments was significantly higher than control treatment in both soils. T_3 produced the highest tuber yield (80.1 ton/ha in SCL soil and 54.6 ton/ha in LS soil), while T_1 produced the lowest tuber yield (42.8 ton/ha in SCL soil and 29.6 ton/ha in LS soil). In SCL soil, the highest and the lowest starch content of cassava tuber were obtained from T_3 and T_1, respectively, but there were no significant differences among treatments in LS soil. The highest and the lowest values of water use efficiency (WUE) and fertilizer use efficiency (FUE) were found from T_3 and T_1 in both soils.

3.2 Introduction

Cassava (*Manihot esculenta* Crantz) is one of the representatives of commercial crops. The related data showed that around 40 ton/ha yield of cassava was vanished in Thailand, which was caused by the insect, drought condition, soil texture and nutrient. The drought condition caused the soil water continuously evaporated into the air. The soil texture affected the water holding capacity (WHC) that the available water was holden by soil for crops use, retaining it against the pull of gravity that would cause the water was free to flow downward into a river or canal. If the soil does not hold water or was in a droughty situation, the cassava field would have to be

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continuously irrigated or wait for the rain coming (Vengadaramana and Jashothan, 2012). In fact, most of the arable soils are sandy soils in Northeast Thailand (Hartmann and Chinabut, 2005). To a certain extent, the sandy soil is not only low WHC but also infertile. Whether the drought condition or the soil texture, when the soil moisture content has been reduced, the growth and tuber yield of cassava will be affected.

The amount of annual rainfall was 1100-2200 mm in the northeast of Thailand, and most of the precipitation came from the rainy season (Moroizumi et al., 2009). Watanabe et al. (2004) reported that cassava would grow under the water shortage condition for 5-6 months in the northeast of Thailand due to the lack of rainfall from November to April. Because of the low precipitation and uneven rainfall distribution, coupled with most of the soil is the sandy soil, it often encounters the problem of water shortage that will lead to a decline of yield during the cassava production. Therefore, the additional irrigation is needed for planting cassava, but sometimes the consumption of irrigation water will be increased or wasted. For example, if the amount of irrigation water exceeds the WHC of soil, the excess part will be leaching or evaporate from the soil surface. The water loss from soil is higher than absorption by root. In addition to the soil water loss, soil nutrient will also lose with the disappearing water. In order to solve the problems of water requirement and improve the tuber yield and water use efficiency of cassava, a reliable process of irrigation should be applied such as drip irrigation.

Under the drip irrigation system, water is transported to the root zone by the plastic pipes, which can prevent water loss from the leaching and evaporation. Odubanjo et al. (2011) found that drip irrigation cassava with 100% 50% and 25%

available water achieved the average yield of 28150 kg/ha, 13100 kg/ha and 8530 kg/ha and the average water use efficiency of 18.87 kg/ha/mm, 11.80 kg/ha/mm and 9.96 kg/ha/mm during 2006/2007 cropping season, respectively, compared with rainfed cassava, yield of 4550 kg/ha and water use efficiency of 6.24 kg/ha/mm. Farmers can irrigate substantial field areas quickly with the irrigation system, and the worldwide shortage of irrigation water can be solved (Kafkafi, 2005). There was a lot of information on cassava irrigation, but less attention had been paid to the water requirement and water application pattern for planting cassava with the drip irrigation.

The objectives of this chapter was to investigate the water requirement and water application pattern of cassava under the drip irrigation system in sandy clay loam (SCL) soil and loamy sand (LS) soil and to evaluate the effects of drip irrigation on the water use efficiency (WUE) fertilizer use efficiency (FUE) starch content and yield of cassava.

3.3 Materials and methods

3.3.1 Experimental site description

The field experiments were conducted from March 2015 to February 2016 at the Suranaree University of Technology Farm, Nakhon Ratchasima, Thailand (14°52′ N latitude, 102°0′ E longitude, 230 m above sea level). The soil of experimental site had two textures that one was sandy clay loam (SCL) with the bulk density 1.3 g/cm^3 and porosity 51.1%, and the other was loamy sand (LS) with the bulk density 1.4 g/cm^3 and porosity 50.7%. In this experiment, The SCL soil belongs to the soil group No. 55 and the distinct characteristic is moderate deep soil group to rock wall rock waste rocks or laterite soil reaction is neutral or base good to moderate drainage moderate fertility. While the LS soil belongs to the soil group No. 44, which has distinct characteristic including thick sand soil group arisen from distributaries sediment or coarse grain sediment, the soil reaction is a little acid to neutral, rather much drainage, low fertility (LDD, 2008). Both soils were sampled from the depth of soil layer (0-30 cm) before the experiment began. Table 3.1 revealed that the AWHC of soil varied from 1.61-1.68 mm/cm, and the soil pH and EC values varied from the depth of 30 cm to the soil surface, in the range of 6.61-6.68 32.3-49.6 µS/cm in SCL soil, respectively. However, table 3.2 showed that the AWHC, pH and EC values varied from 0.92-0.99 mm/cm 5.16-5.31, 112.3-119.5 µS/cm in LS soil, respectively. The nutrient status of soil including OM Av.P Ex.K Ex.Ca and Ex.Mg is shown in Table 3.3 and 3.4, which summarizes some main chemical properties of soils.

The chemical properties of applied water are listed in Table 3.5 and 3.6. The high-quality irrigation water with pH 7.67 and EC 331.7 µS/cm in SCL soil was pumped near the experimental site, while the pH and EC were 6.68 and 151.2 µS/cm in LS soil, respectively. The OM content of water was meager (0.002%) in both locations.

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Table 3.1 Some physical properties of SCL soil (0-30 cm depth).

Depth	**Bulk density**	**Porosity**	**AWHC**
	(g/cm^3)	**(%)**	**(mm/cm)**
0-15	1.3	51.1	1.61
15-30	1.3	51.1	1.68

AWHC: available water holding capacity.

Particle density: 2.66 g/cm^3.

Table 3.2 Some physical properties of LS soil (0-30 cm depth).

Depth	Bulk density	Porosity	AWHC
	(g/cm^3)	(%)	(mm/cm)
0-15	1.4	50.7	0.92
15-30	1.4	50.7	0.99

Particle density: 2.84 g/cm^3.

Table 3.3 Some chemical properties of SCL soil (0-30 cm depth).

Depth	pH	EC	OM	Av.P	Ex.K	Ex.Ca	Ex.Mg
		(µS/cm)	(%)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
0-15	6.68	49.6	1.14	18.8	75.3	925.8	234.2
15-30	6.61	32.3	0.95	12.1	40.9	451.3	124.7

EC: electric conductivity; OM: organic matter; Av.P: available P; Ex.K: exchangeable K; Ex.Ca: exchangeable Ca; Ex.Mg: exchangeable Mg.

Table 3.4 Some chemical properties of LS soil (0-30 cm depth).

Depth	pH	EC	OM	Av.P	Ex.K	Ex.Ca	Ex.Mg
		(µS/cm)	(%)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
0-15	5.31	119.5	0.63	2.0	41.4	221.6	114.9
15-30	5.16	112.3	0.60	0.8	23.7	117.3	96.1

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Table 3.5 Some chemical properties of the applied water for SCL soil and LS soil.

Soil texture	pH	EC	OM	P	K	Ca	Mg	Fe	Zn	Cu
		(μS/cm)	(%)				(mg/L)			
SCL	7.67	331.7	0.002	0.023	13.1	11.6	0.05	1.04	0.17	0.001
LS	6.68	151.2	0.002	0.002	2.2	15.7	1.11	0.56	0.13	0.010

3.3.2 Climatic conditions of the experimental site

The site is characterized by a tropical climate (Phiwngam et al., 2016), with three seasons as follows: the rainy season (May to October), winter (October to February) and summer (February to May). The mean annual temperature was 27.8°C (Thai Meteorological Department, 2016) in the 2015-2016 growing seasons, and the average annual rainfall of 900 mm (SCL) and 936.4 mm (LS), respectively, were recorded during the trial period of the years in experimental sites. In general, the peak period of rainfall is concentrated in August and September (Sarakham et al., 2015). During the trial period, two heavy precipitations were monitored in August (176 mm) and September (195 mm), and there were four months in the dry spell from December 2015 to March 2016.

3.3.3 Experimental design and planting method

In both soil, treatments were arranged in a randomized complete block design (RCBD) with four replications. Treatments were:

T_1: rainfed with soil fertilizer application

T_2: drip irrigation with soil fertilizer application

T_3: drip irrigation with fertigation

Two varieties of cassava were observed from March 2015 to February 2016; one was Var. HB 80 planted in SCL soil, and the other was Var. RY 72 planted in

LS soil. The planting date was on 1st March. The plot size was 18 m wide by 20 m long with the row spacing of 1.2 m and the plant spacing of 0.8 m. Planting materials with the high germination rate were obtained from the healthy stakes of cassava. The stakes were cut manually into 25 cm long with eight viable nodes at least, and two-thirds of the length of stake was buried vertically in the 20 cm high ridge of soil (Legese et al., 2011). Pest control was carried out according to the local recommendations, and weeds were controlled manually with a hoe.

3.3.4 Fertilization

Fertilizers that consisted of urea (46-0-0) diammonium phosphate (18-46-0) and potassium chloride (0-0-60) for two times of soil application were spread manually into the 5 cm depth of soil between every two cassavas at the 2^{nd} and 4^{th} month after planting (MAP). Fertilizers that consisted of urea (46-0-0), monoammonium phosphate (12-60-0) and potassium chloride (0-0-60) for six times of fertigation were dissolved into the irrigation water and applied every two weeks since the 2^{nd} MAP. The amount of applied fertilizer was presented in Table 3.6 according to the Department of Agriculture (DOA) recommendation, which was based on the soil test and usually recommended under the rainfed condition.

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Table 3.6 Amount of fertilizer used in SCL and LS soil.

Soil texture	**N (kg/ha)**	**P_2O_5 (kg/ha)**	**K_2O (kg/ha)**
SCL	50	25	50
LS	100	50	50

3.3.5 Experimental irrigation regime

In both locations, no water was applied to T_1 (rainfall condition), while T_2 and T_3 were applied by the drip irrigation system, which was installed before cassava planting. The central unit of drip irrigation system consisted of a well-using pump, a venturi injector, a control valve, two sub-valves, two filters, a pressure gauge and a water flow meter. Drip tape (Φ = 16 mm) with discharge rate 2 l/h and drippers spacing 30 cm was used. In T_2 and T_3, water was applied at the level of field capacity of soil. When the cassava absorbed 50% of the available water, the soil was re-watered to the field capacity again. The root depth of 10 cm and 20 cm were used to calculate the water requirement of cassava in the 1st and 2nd month, after that the root depth of 30 cm was used from the 3rd month until the harvest (Table 3.7 and 3.8). When it rained, Daily Soil Moisture Balance Method (FAO, 1998) was used to calculate the effective rain, and irrigation pattern was readjusted according to the amount of effective rain. The last month irrigation was not applied. The ETc model (Allen et al., 1998) was used to calculate the cassava water requirement, irrigation frequency and duration, as follow:

$$ETc = ETp \times Kc \tag{1}$$

Where ETc: the amount of water requirement of the crop (mm/day) ETp: the amount of water consumed by standard crops or reference crops (i.e., grass or alfalfa covered with soil throughout the year) (mm) Kc: crop coefficient that used to adjust the value of reference ET. An average ETp of 10 years was used in this experiment (2004-2014).

The predicted moisture content was calculated using the water balance equation (2):

$$PMC_{n+1} = MC_n - \frac{(ETc - ER)\times 100}{D} \qquad (2)$$

Where PMC_{n+1}: predicted moisture content (%) MC_n: moisture content (%) ETc: the amount of water requirement of the crop (mm/day) ER: the amount of effective rain (mm/day) D: the depth of the root (mm), n: the predicted day. The field capacity (31%) was used as moisture content in the first day; it recalculated the predicted moisture content from the field capacity when the amount of effective rain was equal WHC of the soil; the soil was re-watered to field capacity again when the soil moisture reduced to 50% of available water (22.8%).

Table 3.7 Water requirement of cassava in SCL soil.

Age	**ETp**	**Kc**	**ETc**	**Root depth**	**Root AWHC**	**Frequency**	**Duration**
	(mm)		**(mm/day)**	**(cm)**	**(mm)**	**(days)**	**(hours)**
Mar.	4.39	0.30	1.32	10	16.5	6	1.5
Apr.	4.64	0.45	2.09	20	33.0	8	3.0
May.	4.20	0.65	2.73	30	49.5	9	4.5
Jun.	3.95	1.10	4.35	30	49.5	6	4.5
Jul.	3.89	1.10	4.28	30	49.5	6	4.5
Aug.	3.79	1.10	4.17	30	49.5	6	4.5
Sep.	3.36	1.10	3.70	30	49.5	7	4.5
Oct.	3.42	1.10	3.76	30	49.5	7	4.5
Nov.	3.51	0.90	3.16	30	49.5	8	4.5
Dec.	3.41	0.70	2.39	30	49.5	10	4.5
Jan.	3.37	0.50	1.69	30	49.5	15	4.5
Feb.	3.95	0.00	0.00	30	49.5	0	0

AWHC = 1.65 mm/cm ;Drip rate = 5. 56mm/h.

Table 3.8 Water requirement of cassava in LS soil.

Age	ETp (mm)	Kc	ETc (mm/day)	Root depth (cm)	Root AWHC (mm)	Frequency (days)	Duration (hours)
Mar.	4.39	0.30	1.32	10	9.5	4	0.9
Apr.	4.64	0.45	2.09	20	19.0	5	1.7
May.	4.20	0.65	2.73	30	28.5	5	2.6
Jun.	3.95	1.10	4.35	30	28.5	3	2.6
Jul.	3.89	1.10	4.28	30	28.5	3	2.6
Aug.	3.79	1.10	4.17	30	28.5	3	2.6
Sep.	3.36	1.10	3.70	30	28.5	4	2.6
Oct.	3.42	1.10	3.76	30	28.5	4	2.6
Nov.	3.51	0.90	3.16	30	28.5	5	2.6
Dec.	3.41	0.70	2.39	30	28.5	6	2.6
Jan.	3.37	0.50	1.69	30	28.5	8	2.6
Feb.	3.95	0.00	0.00	30	28.5	0	0

AWHC = 0.95 mm/cm ;Drip rate = 5. 56mm/h.

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3.3.6 Soil preparation and analysis

Soil samples were mixed with the coning and quartering method (Campos-M, and Campos-C, 2017) for the physical and chemical properties analysis of soil. Soil texture was determined by the hydrometer method (Bouyoucos, 1962). Bulk density was determined by the clod method (Blake and Hartge, 1986). Presser plate was used to determine the field capacity and permanent wilting point, in order to calculate the AWHC. Electrical conductivity was determined in a 1:5 soil: water ratio by the conductivity meter (He et al., 2012). Soil pH was determined in a 1:1 soil:

water ratio by pH meter (McLean, 1982). Soil organic matter was determined by the Walkley-Black acid digestion method (Walkley, 1947). Available P was determined by the Bray II method (Bray and Kurtz, 1945). Atomic absorption spectrophotometer was used to determine the exchangeable K Ca and Mg (David, 1960), which were extracted with the ammonium acetate at pH 7.0. Micronutrient including Fe Zn and Cu were analyzed by the DTPA method (Lindsay and Norvell, 1978).

3.3.7 Data measurement

All treatment data were collected from both soils of the experiment. Soil moisture (volumetric soil moisture content) was measured every day at 0-40 cm by moisture meter (Soil moisture profile probe, PR2/6, Delta-T-Devices) in the 3rd and the 4th month after planting. Plant height was measured directly in situ from the soil surface to the leaf tip of cassava in the 4th month after planting. Nutrient status of cassava leaf tissue (destructive collection of the two plants per treatment) was analyzed in the 4th month after planting, including wet digestion of N P K Ca Mg and S. At the harvest, Total yield, tuber number, and starch content were collected from the size of sampled area 15×15 m^2. Water use efficiency (WUE) and fertilizer use efficiency (FUE) were calculated by following equations:

$$WUE = \frac{TY1}{WS} \tag{3}$$

$$FUE = \frac{TY2}{FS} \tag{4}$$

Where WUE: the water use efficiency (kg/m^3), FUE: fertilizer use efficiency (ton/kg), TY1: the tuber yield (kg), TY2: the tuber yield (ton), WS: the amount of water supply (m^3), FS: the amount of fertilizer supply (kg).

3.3.8 Calculations and statistical analysis

Data were analyzed using SPSS Statistics 22 with General linear model (Allen et al., 2014). In all analyses, mean values were compared using Ducan's multiple range tests and the significant differences were tested at P-value < 0.05.

3.4 Results and discussion

3.4.1 Water requirement and water supply

Using the water pattern graph to study and analyze the water supply for planting cassava was simple and straightforward. Fig 3.1 and 3.2 showed the amount of water requirement, water supply and rainfall for cassava production in SCL soil and LS soil, respectively. The same total water requirement of 1025 mm was calculated from planting to harvesting (a year data) in both soils because the same Kc was used for the evapotranspiration potential (ETc), which already had been used for water balance in many plants such as coffee crop (Bruno et al., 2007) onion (Zayton, 2007) barley (Mamnouie et al., 2010) tomato (Chanthai et al., 2012) chili (Chanthai and Wonprasaid, 2016). The water requirement increased with the age of cassava until July (the 5th month of growth) when it reached the maximum value of 133 mm. The high values of water requirement were found from June to October, after that, the water requirement decreased from 94.8 to 0 mm. There was a water requirement of 0 mm in the last month because cassava needed a dry condition for the starch accumulation, which was researched in field-grown potato plants by Davies et al. (1989) who summarized that the imposition of water stress could increase the starch content.

Total rainfall of 936 and 911 mm was measured in SCL soil and LS soil, respectively, and the highest rainfall of 195 mm appeared in September. Odubanjo et al. (2011) stated that the amount of rainfall was more than 1000 mm was optimum for high yield production of cassava in tropical areas. Therefore, the supplementary irrigation was inevitable for increasing the yield of cassava in Northeast Thailand.

The amount of water supply was calculated according to the water requirement of cassava and the effective rainfall that was calculated by the Daily Soil Moisture Balance Method (FAO, 1998), which was about 50-90% of rainfall in both soils. As seen in Fig 3.1 and 3.2, cassava required eight months of water supply throughout the year. The highest water supply given to the SCL soil was 79.3 mm in July, but to the LS soil was 90.9 mm in June. The total amount of water supply for the LS soil of 403 mm was higher than the SCL soil of 373 mm. There were relationships between water requirement, water supply and rainfall. When the total water requirement of cassava was definite, the more rainfall was, the less supplied water needed, whereas the less rainfall was, the more supplied water needed.

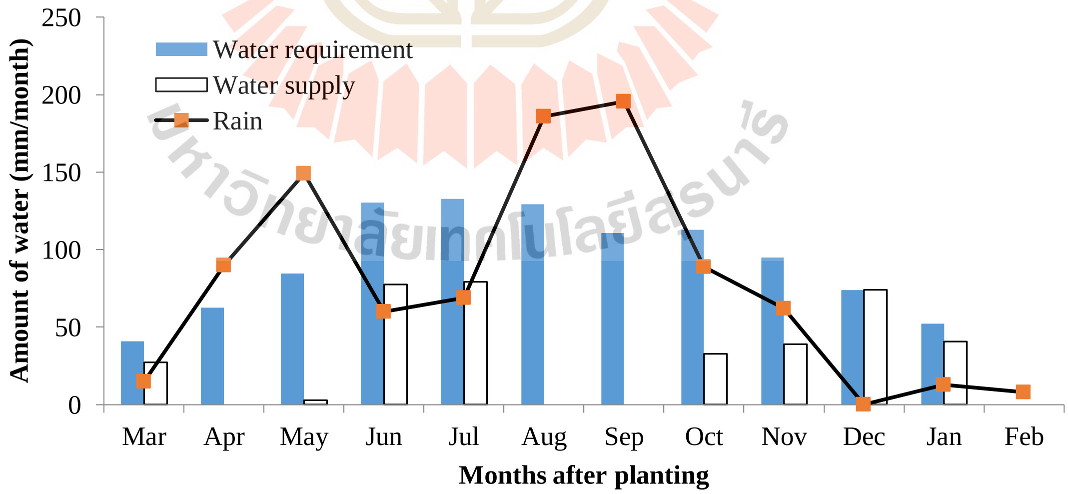

Fig 3.1 Temporal variation of rain, cassava water requirement and water supply in SCL soil.

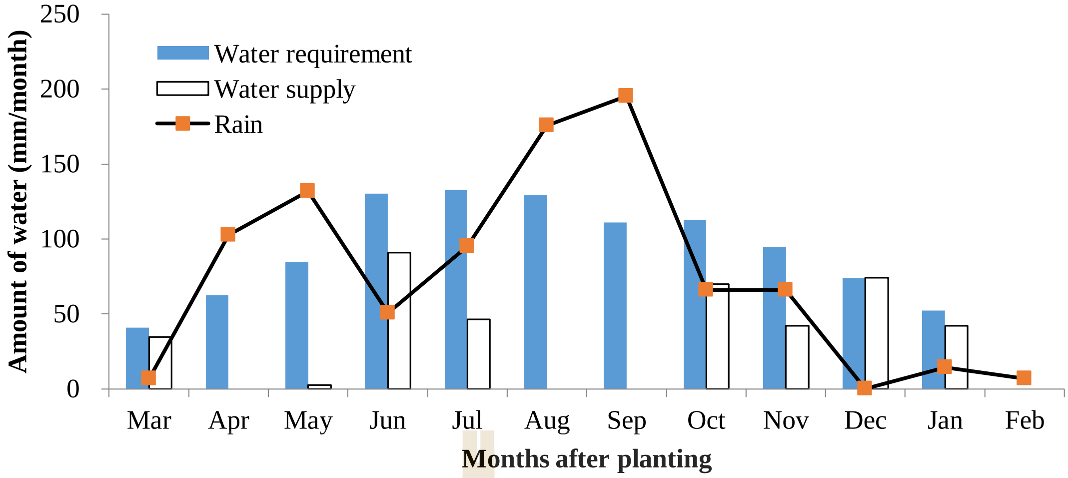

Fig 3.2 Temporal variation of rain, cassava water requirement and water supply in LS soil.

3.4.2 Soil moisture during the growing season of cassava

Fig 3.3 showed the daily soil moisture content that was used to evaluate the differences between control (T_1) and drip irrigation (T_2) during the 3^{rd} and 4^{th} MAP in SCL soil. The maximum soil moisture (31-34%) of T_1 was recorded after the rainfall, which occurred two times during the monitoring period. The lowest moisture content range of T_1 was 12-14%, which was lower than the permanent wilting point (14.5%). In the 62-day-monitoring T_1, there were 39 days below the 50% of available soil water (water deficiency), and eight days below the permanent wilting point (seriously water deficiency). Cassava will reduce the delivery of water to the leaf canopy due to the limited soil moisture. The direct results are the partial closure of leaf stomata, and the top biomass decreases, especially in the early stage of growth. Santisopasri et al. (2001) stated that the yield and starch quality of cassava were affected by water stress for the first six months. Normally, irrigation should be used to alleviate the shortage of soil moisture.

However, comparing with T_1, T_2 was irrigated with the frequency of every other six days using drip irrigation. The average soil moisture content of T_2 (25.8%) was higher than T_1 (19.1%). Soil moisture content of T_2 gradually decreased to 20-21% before irrigated, but after the drip irrigation, it returned to 29-31%, closed to the field capacity (31%). There were discontinuous 15 days below the 50% of available soil water (water deficiency) in T_2. The additional irrigation of T_2 was applied to bring the soil moisture content nearby the field capacity by the drip irrigation. The different soil moisture content between rainfed and drip irrigation would reflect the differences in the growth and tuber yield of cassava. Cassava height, stem diameter, tuber number and tuber yield decreased with a decline in the percentage of field capacity (Aina et al., 2007). When the soil moisture content declines to the permanent wilting point, soil water is not enough for the roots absorption and to sustain the plant life (Cassel and Nielsen, 1986).

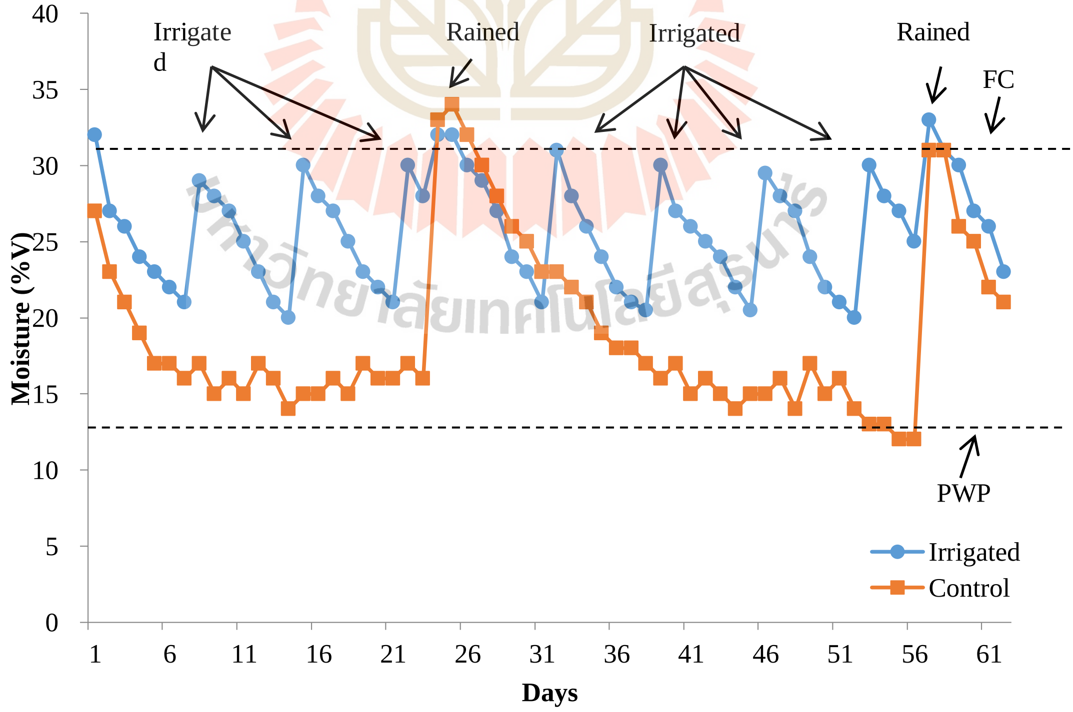

Fig 3.3 Soil moisture content during the 3rd and 4th MAP in SCL soil.

3.4.3 Predicted and measured soil moisture content

The predicted moisture content of soil was calculated from equation 2 (section 3.3.5) during the 3rd and 4th MAP. The predicted moisture content was 22-31%, but the measured moisture content was 20-33%. In fact, the predicted moisture is a product from the idealization irrigation, which maintained the highest soil moisture content to field capacity and the lowest content at 50% of the available water level. As a result, the predicted moisture content was slightly higher than the measured moisture content, especially before every irrigated event, but the variation of moisture content was nearly consistent. The data for prediction cannot be exactly same as the original data, and a slight deviation can be accepted. However, the consistent change tendency was existent between the predicted and the measured moisture content in the experimental plot (Figure 3.4). When the regression analysis of moisture content was tested between the predicted and the measured, highly correlate with R^2 = 0.8 was found (Figure 3.5). The output of predicted moisture content was used to illustrate the practical statistical procedures for the drought frequency, duration, and severity. (Smart, 1983). The results of predicted moisture content reflected that it was reasonable and applicable for the drip irrigation using the predicted equation (2).

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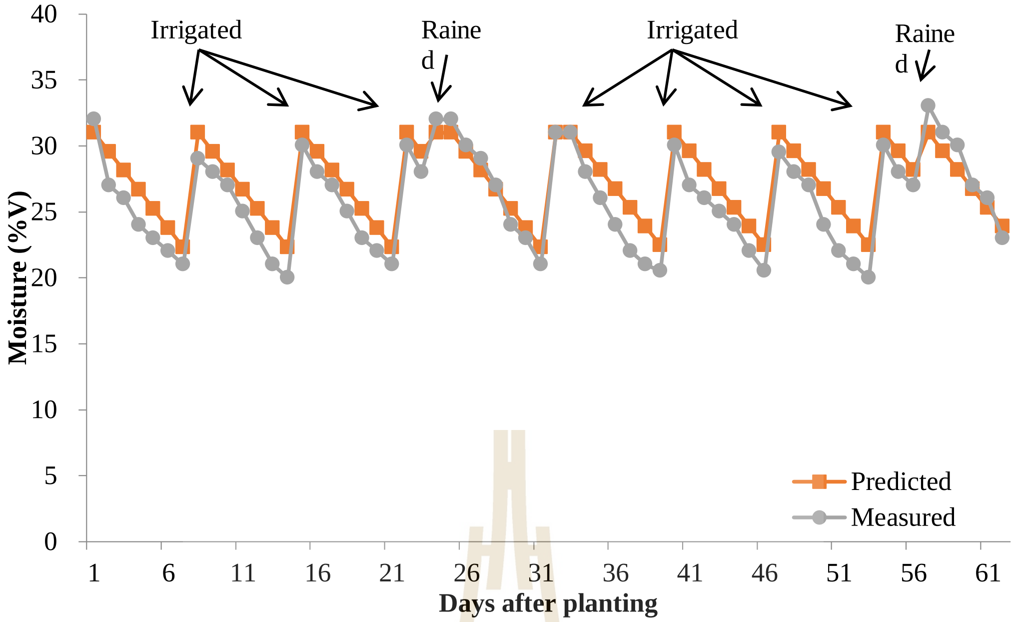

Fig 3.4 Predicted and measured soil moisture content during the 3rd and 4th MAP in SCL soil.

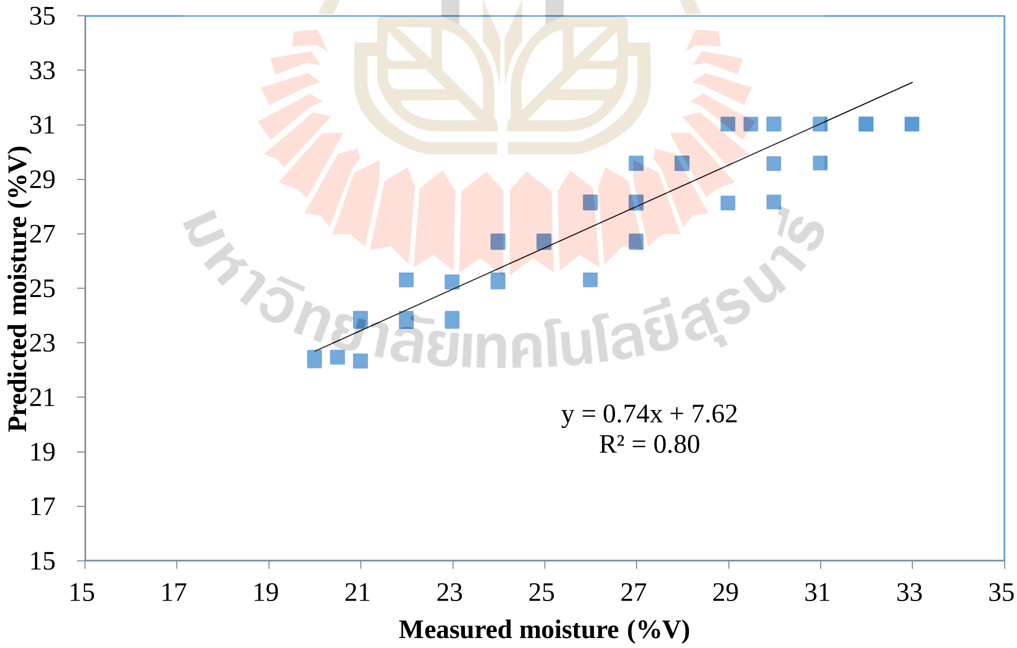

Fig 3.5 Relationship between predicted and measured soil moisture content during the 3rd and 4th MAP in SCL soil.

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3.4.4 Plant height and leaf tissue nutrient

Table 3.9 presented the plant height and leaf tissue nutrient at the 4^{th} MAP in SCL soil. The highest and the lowest plant height were observed from T_3 and T_1, respectively. The height of T_3 under the drip fertigation was 149 cm and significant difference compared with T_1, which was 125 cm under the rainfed. The difference in plant height between T_2 (147 cm) and T_3 (149 cm) was not significant, which was 17.6% and 19.2% higher than T_1, respectively. Table 3.10 showed the plant height and leaf tissue nutrient in LS soil. There was no significant difference between T_2 and T_3. The height of cassava was 138-140 cm under the drip irrigation, which was 16.9%-18.6% significantly higher than the rainfed T_1 of 118 cm ($P < 0.05$). The results indicated that the drip irrigation promoted the height of cassava in both soils but the increasing rate in SCL soil was higher than in SL soil. Olanrewaju et al. (2009) reported similar results of improvement in the height of cassava through drip irrigation at full (100% AW) or medium irrigation (60% AW) level. Zhang et al. (2010) also reported that drip irrigation obtained the height of cassava 260 cm in the 4^{th} MAP, which was 15 cm higher than that grown under rainfed.

The results of leaf tissue nutrient analysis of the 4-month-old cassava in Table 3.9 showed that the N content of T_3 (5.25%) was the highest, whereas T_1 (4.75%) was the lowest in SCL soil. The N content of T_2 and T_3 were significantly different from T_1. The P content ranged from 0.32 to 0.37%, and the K content varied from 1.06 to 1.43%. The Ca Mg and S content significantly differed between T_1 and T_3. T_3 had significantly higher Ca Mg and S content than other treatments but did not significantly differ from T_2. However, Table 3.10 presented the difference in N content between T_2 and T_3 of was not significant in LS soil. The highest N content was T_3

(4.89%). The P content ranged from 0.31 to 0.35%, and the K content varied from 0.96 to 1.33%. The Ca content of T_3 was significantly higher than T_1 and T_2, but there was no significant difference in Ca content between T_2 and T_3. The Mg content significantly differed between T_1 and T_3. T_3 had significantly higher Mg content than other treatments but did not significantly differ from T_2. The S content of T_2 and T_3 was no significant difference, but it significantly differed higher than T_1. The difference of P content was not statistically significant in both soils. T_3 had significantly higher K content than other treatments and T_1 was the lowest among treatments in both soils.

Comparing the nutrient with the sufficient level, the results showed that T_3 manifested the N and K sufficiency in SCL soil, but the N and K was deficiency in LS soil. T_1 and T_2 presented the N and K deficiency, all treatments of experiment presented the P and Ca deficiency, and The Mg was sufficiency in both soils. T_1 presented the S deficiency, but T_2 and T_3 was sufficiency in both soils (Table 3.9 and 3.10). The results indicated that drip irrigation could promote the cassava root to absorb the soil nutrients, which transported from the roots to the stems and then to the leaves, consequently increased the leaf tissue nutrient of cassava. However, the effect on the amount of nutrient uptake was different. The drip irrigation produced a high impact on N K Ca Mg and S content in the leaves, while it had a small impact on P content. In general, drip fertigation is more effective than soil fertilizer application in improving the nutrient content of leaves. There are two aspects of the above results. On the one hand, the amount of soil moisture deficiency limits the transport of nutrients to leaves of cassava, especially in the semiarid area. The drip irrigation can effectively control the soil moisture content between 50% of available water and field capacity, and it can promote soil nutrient conversion and facilitate absorption and utilization of cassava. On the other hand, fertigation can accurately maintain the fertilizer around the rhizosphere where the water goes (Assouline, 2002; Bar-Yosef, 1999), which promotes effective nutrient absorb by cassava. Thiyagarajan et al. (2011) reported that drip fertigation enabled the slow and precise application of water and nutrients to the precise locations.

Table 3.9 Plant height and nutrient of leaf tissue at the 4th MAP in SCL soil.

Treatment	**Plant height**	**N**	**P**	**K**	**Ca**	**Mg**	**S**
	(cm)	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**
T1	125b	4.75b	0.32	1.06c	0.39b	0.30b	0.29b
T2	147a	5.05a	0.37	1.39b	0.41ab	0.32ab	0.31ab
T3	149a	5.25a	0.35	1.43a	0.45a	0.34a	0.33a
Sufficient level (%)		5.10	0.38	1.42	0.50	0.24	0.30
C.V. (%)	6.1	7.2	5.9	7.3	8.1	7.5	7.1

Means in the same columns followed by the different letters indicate statistically significant differences as according to Duncan's multiple range test at $P < 0.05$.

Table 3.10 Plant height and nutrient of leaf tissue at the 4th MAP in LS soil.

Treatment	Plant height	N	P	K	Ca	Mg	S
	(cm)	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**
T1	118b	4.15b	0.31	0.96c	0.30b	0.31b	0.25b
T2		4.35b	0.35	1.28b		0.33a	
	138a				0.35b	b	0.31a
T3	140a	4.89a	0.33	1.33a	0.42a	0.35a	0.32a
Sufficient level (%)		5.10	0.38	1.42	0.50	0.24	0.30
C.V. (%)	7.3	5.6	4.9	5.6	5.8	5.7	4.3

Means in the same columns followed by the different letters indicate statistically significant differences as according to Duncan's multiple range test at $P < 0.05$.

3.4.5 Tuber number, yield and starch content

The tuber number, yield and starch content of cassava were obtained at the 12-month-old in both soils. The results in Table 3.11 showed that the tuber yield varied from 42.8 to 80.1 ton/ha in SCL soil. T_3 had significantly higher yield than other treatments, whereas T_1 was the lowest. However, in Table 3.12 the tuber yield of cassava varied from 29.6 to 54.6 ton/ha in LS soil. The yield of T_2 and T_3 were significantly higher than T_1, whereas the difference in yield between T_2 and T_3 was not significant. Compared with control, both drip soil fertilizer application and drip fertigation were able to obtain the significant increase of tuber yield of cassava and the increasing rate reached 70.3% and 87.2% in SCL soil, 60.5% and 84.5% in LS soil, respectively. The tuber number varied from 10.2 to 17.4 per plant in SCL soil in Table

3.11 and from 7.0 to 14.0 in LS soil in Table 3.12. T_3 had significantly higher tuber number than other treatments, whereas T_1 was the lowest in both soils ($P < 0.05$). Normally, the root development of cassava is significantly inhibited under drought or waterlogging. The drought affects the absorption and utilization of nutrients due to the lack of soil water; the growth of tuberous roots needs to overcome and resist the soil hardness. The waterlogging inhibits the growth of roots and tuberous roots, causes roots rot and starch content decline due to the excessive soil moisture, resulting in the reduced cassava yield and tuber number. In this study, the drip irrigation not only satisfied the water requirement of cassava but also prevented the lacking or excessive soil moisture causing a decline in cassava yield. Drip irrigation regimes affected the yield of tuber crops such as potato (Ierna and Mauromicale, 2012; Kang et al., 2004; Foti et al., 1995). Yuan et al. (2003) also reported that drip-irrigated potato at the 1.25 times of evaporation (Ep) obtained the highest yield of 1.09 kg per plant, which was close to the theoretical maximum. Odubanjo et al. (2011) also reported that drip-irrigated cassava with receiving 100% available water produced the highest average total dry matter yield of 49.1 and 37.6 t/ha in 2006/07 and 2007/08 cropping seasons in the tropical area, respectively.

In table 3.11, the highest and the lowest tuber starch content were found from the T_3 and T_2 in SCL soil, respectively. The starch content of T_3 (31.9%) under the drip irrigation was significant difference compared with T_1 (28.5%) under the rainfed. The difference in starch content between T_2 and T_3 was not significant, which were 11.9% higher than T_1. However, in Table 3.12, the starch content ranged from 28.5 to 29.1% in LS soil, and no significant differences were found among treatments ($P < 0.05$). The irrigation promotes the growth of cassava and also ensures the water requirement of cassava, but sometimes reduces the tuber starch content of cassava. Zhang et al. (2001) reported that the higher amount of irrigation caused the lower starch content of cassava. However, if the amount of irrigation water is accurate enough, the starch content should be maintained at high level. In this study, both starch contents of drip-irrigated cassava of 31.90% in SCL soil and 28.8-29.1% in LS soil were higher than that of 27.8%, which was determined by Santisopasri et al. (2001) in Thailand. The characteristics of starch were varied under the different environmental conditions and periods. Santisopasri et al. (2001) reported that water stress influenced the starch metabolism in all six varieties of cassava and changed the starch properties such as smaller mean size and distribution, especially in the early drought period. Actually, the size of starch granule was increased in all the six varieties of cassava up to the 6th month from the time of tuber initiation and after that remained almost constant (Moorthy and Ramanujam, 1986).

Table 3.11 Tuber number, yield and starch content at harvesting in SCL soil.

Treatment	Tuber number (per plant)	Yield (ton/ha)	Starch (%)
T1	10.2c	42.8c	28.5b
T2	14.7b	72.9b	31.9a
T3	17.4a	80.1a	31.9a
C.V. (%)	7.8	6.4	4.9

Means in the same columns followed by the different letters indicate statistically significant differences as according to Duncan's multiple range test at $P < 0.05$.

Table 3.12 Tuber number, yield and starch content at harvesting in LS soil.

Treatment	Tuber number (per plant)	Yield (ton/ha)	Starch (%)
T1	7.0c	29.6b	28.5
T2	11.9b	47.5a	29.1
T3	14.0a	54.6a	28.8
C.V. (%)	7.2	7.4	5.9

Means in the same columns followed by the different letters indicate statistically significant differences as according to Duncan's multiple range test at $P < 0.05$.

3.4.6 Water and fertilizer use efficiency

The water use efficiency (WUE) and fertilizer use efficiency (FUE) of different treatments were listed in Table 3.13 and 3.14. The results in Table 3.13 showed that the highest and the lowest WUE in SCL soil were found in T_3 and T_1, respectively. The WUE of T_3 under the drip fertigation was 7.82 kg/m^3 and significant difference compared with T_1, which was 5.86 kg/m^3 under the rainfed. The difference in WUE between T_2 and T_3 was not significant, which was 21.5% and 33.5% higher than T_1, respectively. However, in Table 3.14, T_3 (5.33 kg/m^3) was the highest, and T_2 (4.64 kg/m^3) came second, whereas T_1 (4.16 kg/m^3) was the lowest in LS soil. The WUE of T_2 did not significantly differ from T_3, and the same result was found in the comparison of T_1 and T_2, but T_3 significantly differed from T_1. Compared with control, drip fertigation was able to obtain a significant increase of WUE, and the increasing rate reached 28.1% ($P < 0.05$). The results indicated that the drip irrigation had ability to increase the WUE of cassava. Water dripped to a single plant was very effective in water use, and it was most suitable for the situations when and where the water was scarce (Brouwer et al., 1988). Drip irrigation not only reduces the amount of water supplied but also reduces the surface water evaporation and avoids the water ponding and runoff, and hence it significantly saves the irrigation water and improves the water use efficiency. Olanrewaju et al. (2009) reported that the highest water use efficiency of 23.63 kg/ha per mm was obtained from the 60% AW treatment compared with the control of 19.66 kg/ha per mm. The results were in agreement with the report on the water use efficiency in several researches (Du et al., 2008; Deng et al., 2006; Kang et al., 2001).

The FUE consisted of N, P and K use efficiency, which abbreviated as NUE, PUE and KUE, respectively. The NUE, PUE and KUE in T_2 and T_3 were significantly higher than T_1 in both soils, but the difference in FUE between T_2 and T_3 was not significant ($P < 0.05$). The results could be explained from the fact that the nutrients from the soil fertilizer application were not released completely, and crops were hard to use the part of them, which were bundled by the soil. However, fertigation had the high ability of quickly dissolved nutrient, which was suitable for the cassava uptake, thereby the fertilizer use efficiency was enhanced. Sharmasarkar et al. (2016) reported that the water use efficiency and fertilizer use efficiency of drip irrigation were higher than flood irrigation. Wu et al. (2016) also reported that drip fertigation increased the NUE, PUE and KUE by 22.7% 20.5% and 23.5% in potato, respectively, and the PUE was higher than the NUE and KUE.

Table 3.13 Water and fertilizer use efficiency in SCL soil.

Treatment	WUE (kg/m^3)	FUE (ton/kg)		
		N	P_2O_5	K_2O
T1	5.86b	0.86b	1.71b	0.86b
T2	7.12a	1.46a	2.92a	1.46a
T3	7.82a	1.60a	3.20a	1.60a
C.V. (%)	6.7	7.5	7.3	7.5

Means in the same columns followed by the different letters indicate statistically significant differences as according to Duncan's multiple range test at $P < 0.05$.

Table 3.14 Water and fertilizer use efficiency in LS soil.

Treatment	WUE (kg/m^3)	FUE (ton/kg)		
		N	P_2O_5	K_2O
T1	4.16b	0.30b	0.59b	0.59b
T2	4.64ab	0.48a	0.95a	0.95a
T3	5.33a	0.55a	1.09a	1.09a
C.V. (%)	7.7	7.6	7.3	7.3

Means in the same columns followed by the different letters indicate statistically significant differences as according to Duncan's multiple range test at $P < 0.05$.

3.4.7 Combined analysis

The results of combined analysis in Table 3.15 showed that the yield, starch content and water use efficiency (WUE) were not affected by the interaction between site and treatment, but fertilizer use efficiency (FUE) was affected by the

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interaction between them ($P < 0.05$). This interaction result revealed that comprising the drip fertigation together with the SCL soil gave the highest FUE. Comparing the two experimental sites, the SCL soil was highly significantly better than LS soil. The highest tuber yield (65.3 ton/ha), tuber starch content (30.8%) and WUE (6.93 kg/m^3) were obtained in the SCL soil, and the lowest yield (43.9 ton/ha), starch content (28.8%) and WUE (4.71 kg/m^3) were obtained in the LS soil ($P < 0.01$). The SCL soil has more excellent physical properties such as soil porosity and aggregate, water holding capacity and infiltration rate, and cation exchange capacity. It also contains steadier chemical properties such as organic matter, available P and exchangeable K compared to LS soil. Hamza and Anderson (2003) reported that the yield responses of wheat, pea and chickpeas were significant more in LS soil than in SCL soil, which was contrary to this study.

However, when the experimental treatments were compared, the cassava tuber yield (67.31 ton/ha), tuber starch content (31.37%) and WUE (6.27 kg/m^3) of T_3 were the highest, while yield (36.19 ton/ha), starch content (28.50%), and WUE (4.80 kg/m^3) of T_1 were the lowest ($P < 0.01$). Cassava yield, starch content, WUE in T_2 and T_3 were highly significantly higher than T_1, but the differences in starch content and WUE between T_2 and T_3 were not significant ($P < 0.01$). NUE, PUE and, KUE in T_2 and T_3 were highly significantly higher than T_1 ($P < 0.01$). The overall results of this study were similar to the other researches. Manickasundaram et al. (2002) reported that when drip fertigation was applied once in two days at 60% of pan evaporation, yield and water use efficiency of turmeric would be enhanced. Janat (2007) reported that drip fertigation could improve the nitrogen use efficiency and yield of potato. The result of drip fertigation showed that the threefold increase in the tuber yield of cassava at 100% of pan evaporation along with 50% N and K fertilizers during the first 40 days, 30% during the 40-80 days and the rest 20% during the 80-120 days after planting (James and Sreekumar, 2015).

Table 3.15 Combined analysis of tuber yield, tuber starch content, water use efficiency and fertilizer use efficiency.

Variable	Yield (ton/ha)	Starch (%)	WUE (kg/m^3)	FUE (ton/kg)		
				N	P_2O_5	K_2O
Site	**	**	**	**	**	**
SCL	65.3a	30.8a	6.93a	1.31a	2.61a	1.31a
LS	43.9b	28.8b	4.71b	0.44b	0.88b	0.88b
Treatment	**	**	**	**	**	**
T1	36.2c	28.5b	4.80b	0.58c	1.15c	0.72c
T2	60.2b	30.5a	5.60a	0.97b	1.94b	1.20b
T3	67.3a	31.4a	6.27a	1.08a	2.15a	1.35a
Site × Treatment	ns	ns	ns	*	*	*

Means in the same columns followed by the different letters indicate significant differences as statistically according to Duncan’s multiple range test.

*: significant at P < 0.05.

**: significant at P < 0.01.

ns: not significant.

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3.5 Conclusion

The results of this study confirmed that different water regimes through drip the irrigation based on the Kc model and water balance equation affected the cassava tuber yield. The soil moisture content could be predictable with the water balance equation, which was used for the drip irrigation cassava. In this study, it has revealed that in the northeast region of Thailand, the drip fertigation can be used for achieving higher tuber yield of cassava, increasing the tuber starch content and enhancing water and fertilizer use efficiency. Furthermore, in this region where water is very scarce, the drip fertigation can be applied to obtain a higher yield than the rainfed soil fertilizer application. Compared with the rainfed (T_1), both drip irrigation treatments (T_2 and T_3) were able to increase the cassava yield, and the increasing rate reached 70.3% and 87.2% in SCL soil, 60.5% and 84.5% in SL soil, respectively. The increasing rate of WUE reached 21.5% and 33.5% in SCL soil, 11.5% and 28.1% in LS soil, respectively. As a result, the best yield and quality of cassava under the tropical climatic should be taken through the drip fertigation. A suitable drip irrigation program is used as a suggestion to the farmers in Northeast Thailand. However, because the area of sandy soils is more than clay soils, fertigation cassava in sandy loam soil was also a feasibility suggestion.

3.6 References

Allen, P., Bennett, K., & Heritage, B. (2014). **SPSS statistics version 22: A practical guide**. Cengage Learning Australia.

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). FAO Irrigation and drainage paper No. 56. **Rome: Food and Agriculture Organization of the United Nations**.

56(97): e156.

Aina, O. O., Dixon, A. G., & Akinrinde, E. A. (2007). Effect of soil moisture stress on growth and yield of cassava in Nigeria. **Pakistan Journal of Biological Sciences: PJBS**. 10(18): 3085-3090.

Assouline S. (2002). The effects of microdrip and conventional drip irrigation on water distribution and uptake. **Soil Science Society of America Journal**. 66: 1630-1636.

Bar-Yosef, B. (1999). Advances in fertigation. **In Advances in Agronomy**. Academic Press. 1-77.

Blake, G.R., Hartge, K.H. (1986). Bulk density. **In: Klute, A. (Ed.), Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods, second ed**. ASA and SSSA, Madison, WI, USA. 363-375.

Bouyoucos, G. J. (1962). Hydrometer method improved for making particle size analyses of soils. **Agronomy Journal**. 54(5): 464-465.

Bray, R. H., & Kurtz, L. T. (1945). Determination of total, organic, and available forms of phosphorus in soils. **Soil Science**. 59(1): 39-46.

Brouwer, C., Prins, K., Kay, M., & Heibloem, M. (1988). Irrigation water management: irrigation methods. **Training Manual**. 9.

Bruno, I. P., Silva, A. L. D., Reichardt, K., Dourado-Neto, D., Bacchi, O. O. S., & Volpe, C. A. (2007). Comparison between climatological and field water balances for a coffee crop. **Scientia Agricola**. 64(3): 215-220.

Campos-M, M., & Campos-C, R. (2017). Applications of quartering method in soils and foods. **International Journal of Engineering Research and Applications**. 7(1): 35-39.

มหาวิทยาลัยเทคโนโลยีสุรนารี

Cassel, D. K., & Nielsen, D. R. (1986). Field capacity and available water capacity. **Methods of Soil Analysis: Part 1—Physical and Mineralogical Methods, (methodsofsoilan1)**. 901-926.

Chanthai, S., Machikowa, T., Wonprasaid, S., & Boonkerd, N. (2012, May). Effects of fertigation, water application frequency and soil amendment on tomato production. In **VII International Symposium on Mineral Nutrition of Fruit Crops 984**. 187-195.

Chanthai, S., & Wonprasaid, S. (2016). Effects of Fertigation and Water Application Frequency on Yield, Water and Fertilizer Use Efficiency of Chili (Capsicum annuum L.). **Int'l Journal of Research in Chemical, Metallurgical and Civil Engg**. 209-213.

David, D. J. (1960). The determination of exchangeable sodium, potassium, calcium and magnesium in soils by atomic-absorption spectrophotometry. **Analyst**, 85(1012): 495-503.

Davies, H. V., Jefferies, R. A., & Scobie, L. (1989). Hexose accumulation in cold-stored tubers of potato (Solanum tuberosum L.): The effects of water stress. **Journal of Plant Physiology**. 134(4): 471-475.

Deng, X. P., Shan, L., Zhang, H., & Turner, N. C. (2006). Improving agricultural water use efficiency in arid and semiarid areas of China. **Agricultural Water Management**. 80(1-3): 23-40.

Du, T., Kang, S., Zhang, J., Li, F., & Yan, B. (2008). Water use efficiency and fruit quality of table grape under alternate partial root-zone drip irrigation. **Agricultural Water Management**. 95(6): 659-668.

Foti, S., Mauromicale, G., & Ierna, A. (1995). Influence of irrigation regimes on growth and yield of potato cv. Spunta. **Potato Research**. 38(4): 307-317.

Hamza, M. A., & Anderson, W. K. (2003). Responses of soil properties and grain yields to deep ripping and gypsum application in a compacted loamy sand soil contrasted with a sandy clay loam soil in Western Australia. **Australian Journal of Agricultural Research**. 54(3): 273-282.

Hartmann, C., & Chinabut, N. (2005). A holistic approach for sustainable development of problem soils in the tropics: proceedings. **In Management of Tropical Sandy Soils for Sustainable Agriculture**. Khon Kaen, Thailand.

He, Y., DeSutter, T., Prunty, L., Hopkins, D., Jia, X., & Wysocki, D. A. (2012). Evaluation of 1: 5 soil to water extract electrical conductivity methods. **Geoderma**. 185: 12-17.

Ierna, A., & Mauromicale, G. (2012). Tuber yield and irrigation water productivity in early potatoes as affected by irrigation regime. **Agricultural Water Management**. 115: 276-284.

James, G., & Sreekumar, J. (2015). Productivity of Cassava (Manihot esculenta) as affected by drip fertigation in humid tropics. **Journal of Root Crops**. 39(2): 100-104.

Janat, M. (2007). Efficiency of nitrogen fertilizer for potato under fertigation utilizing a nitrogen tracer technique. **Communications in Soil Science and Plant Analysis**. 38(17-18): 2401-2422.

Kafkafi, U. (2005). Global aspects of fertigation usage. In **Fertigation Proceedings, International Symposium on Fertigation**. Beijing, China. 8-22.

Kang, S., Zhang, L., Hu, X., Li, Z., & Jerie, P. (2001). An improved water use efficiency for hot pepper grown under controlled alternate drip irrigation on partial roots. **Scientia Horticulturae**. 89(4): 257-267.

Kang, Y., Wang, F. X., Liu, H. J., & Yuan, B. Z. (2004). Potato Evapotranspiration and Yields under Different Drip Irrigation Regimes. In **2004 ASAE Annual Meeting**. (p 1). American Society of Agricultural and Biological Engineers.

LDD (Land Development Department), 2008. http://www.ldd.go.th/ldd_en/en-US/classification- and-kinds-of-soil/.

Legese, H., Gobeze, L., Shegro, A., & Geleta, N. (2011). Impact of Planting Position and Planting Material on Root Yield of Cassava (Manihot esculenta Crantz). **Journal of Agricultural Science and Technology**. 5(4): 448-454.

Lindsay, W. L., & Norvell, W. A. (1978). Development of a DTPA soil test for zinc, iron, manganese, and copper. **Soil Science Society of America Journal**. 42(3): 421-428.

Mamnouie, E., Fotouhi Ghazvini, R., Esfahani, M., & Nakhoda, B. (2010). The effects of water deficit on crop yield and the physiological characteristics of barley (*Hordeum vulgare* L.) varieties. **Journal of Agricultural Science and Technology**. 8: 211-219.

Manickasundaram, P., Selvaraj, P. K., Krishnamoorthi, V. V., & Gnanamurthy, P. (2002). Drip irrigation and fertigation studies in tapioca. **Madras Agricultural Journal**. 89(7/9): 466-468.

McLean, E. O. (1982). Soil pH and lime requirement. **Methods of soil analysis. Part 2. Chemical and microbiological properties, (methodsofsoilan2)**. 199-224.

Moorthy, S. N., & Ramanujam, T. (1986). Variation in properties of starch in cassava varieties in relation to age of the crop. **Starch-Stärke**. 38(2): 58-61.

Moroizumi, T., Hamada, H., Sukchan, S., & Ikemoto, M. (2009). Soil water content and water balance in rainfed fields in Northeast Thailand. **Agricultural Water Management**. 96(1): 160-166.

Odubanjo, O. O., Olufayo, A. A., & Oguntunde, P. G. (2011). Water use, growth, and yield of drip irrigated cassava in a humid tropical environment. **Soil and Water Research**. 6(1): 10-20.

Olanrewaju, O. O., Olufayo, A. A., Oguntunde, P. G., & Ilemobade, A. A. (2009). Water use efficiency of Manihot Esculenta Crantz under drip irrigation system in South Western Nigeria. **European Journal of Scientific Research**. 576-587.

Phiwngam, A., Anusontpornperm, S., Thanachit, S., & Wisawapipat, W. (2016). Effects of soil moisture conservation practice, irrigation and fertilization on Jatropha curcas. **Agriculture and Natural Resources**. 50(6): 454-459.

Santisopasri, V., Kurotjanawong, K., Chotineeranat, S., Piyachomkwan, K., Sriroth, K., & Oates, C. G. (2001). Impact of water stress on yield and quality of cassava starch. **Industrial Crops and Products**. 13(2): 115-129.

Sarakham, M., Et, R., Chaiyaphum, Y., Charoen, A., Ratchathani, U., Sa, S., ... & Buri, S (2015). **The Climate of Thailand**.

Sharmasarkar, F. C., Sharmasarkar, S., Miller, S. D., Vance, G. F., & Zhang, R. (2001). Assessment of drip and flood irrigation on water and fertilizer use efficiencies for sugarbeets. **Agricultural Water Management**. 46(3): 241-251.

มหาวิทยาลัยเทคโนโลยีสุรนารี

Smart, G. M. (1983). Drought analysis and soil moisture prediction. Journal of **Irrigation and Drainage Engineering**. 109(2): 251-261.

Tahere, A. S., Yamauchi, A., Kamoshita, A., & Wade, L. J. (2000). Genotypic variation in response of rainfed lowland rice to drought and rewatering: II. Root growth. **Plant Production Science**. 3(2): 180-188.

Thai Meteorological Department, 2016. Rainfall and Temperature of Nakhon Ratchasima Province. Source: https://www.tmd.go.th/en/province.php?id=20.

Thiyagarajan, G., Vijayakumar, M., Selvaraj, P. K., Duraisamy, V. K., & Yassin, M. M. (2011). Performance evaluation of fertigation of N and K on yield and water use efficiency of turmeric through drip irrigation. **International Journal of Bioresource and Stress Management**. 2(1): 69-71.

Vengadaramana, A., & Jashothan, P. T. J. (2012). Effect of organic fertilizers on the water holding capacity of soil in different terrains of Jaffna peninsula in Sri Lanka. **J. Nat. Prod. Plant Resour**. 2(4): 500-503.

Walkley, A. (1947). A critical examination of a rapid method for determining organic carbon in soils-Effect of variations in digestion conditions and of inorganic soil constituents. **Soil Science**. 63(4): 251-264.

Watanabe, K., Yamamoto, T., Yamada, T., Sakuratani, T., Nawata, E., Noichana, C., ... & Higuchi, H. (2004). Changes in seasonal evapotranspiration, soil water content, and crop coefficients in sugarcane, cassava, and maize fields in Northeast Thailand. **Agricultural Water Management**. 67(2): 133-143.

Wu, X. H., Zeng, L. H., Li, J. L., Fang, Z. G., Liang, B., & Wei, F. L. (2016). Effects of Different Fertilizer Treatments on Yield, Quality and Fertilizer Utilization

มหาวิทยาลัยเทคโนโลยีสุรนารี

Ratio of Potato under Mulching Drip Irrigation Conditions. **Acta Agriculturae Boreali-Sinica**. 31(5): 193-198.

Yuan, B. Z., Nishiyama, S., & Kang, Y. (2003). Effects of different irrigation regimes on the growth and yield of drip-irrigated potato. **Agricultural Water Management**. 63(3): 153-167.

Zayton, A. M. (2007). Effect of soil-water stress on onion yield and quality in sandy soil. **Irrigation and Drainage**. 24(1): 141-160.

Zhang, T. Q., Wu, W. X., Yang, X. Y., Wei, J. X. & Lin, X. J. (2017). Test and study of efficient utilization of water and fertilizer in cassava drip irrigation in South-western Guangxi. **Guangxi Water Resources & Hydropower Engineering**. 74-78.

Zhang, Y. H., Ye, J., & Li, D. R. (2010). Influence of different irrigation on agronomic traits of Cassava. **Guangdong Agricultural Sciences**. 2, 007.

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CHAPTER IV

OPTIMAL FERTIGATION FREQUENCY AND FERTILIZER RATE FOR CASSAVA PRODUCTION UNDER DRIP IRRIGATION IN TWO DIFFERENT TEXTURED SOILS

4.1 Abstract

This study investigated the effects of different fertigation frequencies and fertilizer rates on cassava production under the drip irrigation system during the 2016-2017 seasons. The experiments were conducted in two textured soils (sandy clay loam (SCL) with Var. HB 80 and loamy sand (LS) with Var. RY 72) at the Suranaree University of Technology Farm, Nakhon Ratchasima, Thailand. The ETc model and water balance equation were used to determine the amount of irrigation water. The study treatments consisted of three fertilization methods (soil fertilizer application fertigation and combination of soil fertilizer application and fertigation), two fertigation frequencies (high frequency and low frequency) and three fertilizer rates (no fertilizer, DOA recommendation and NB model). The results indicated the low-frequency fertigation with NB model positively affected the growth parameters, fresh and dry weight, LAI, CGR and leaf tissue nutrient at 120 DAP in SCL soil. After the 120 DAP, the high-frequency fertigation with NB model dominated the results of cassava production in SCL soil. However, the high-frequency fertigation influenced

the cassava growth from planting to harvesting in LS soil. The highest and the lowest tuber starch content, tuber number and harvest index (HI) were observed from T_5 and T_1 in both soils, respectively. The yield and net income obtained from the high-frequency fertigation with NB model (T_5) were significantly higher than other treatments in both soils. T_5 produced the highest yield and net income (90.1 ton/ha and 117,747 B/ha in SCL soil; 70.2 ton/ha and 70,386 B/ha in LS soil) while the lowest yield and net income were produced by T_1 (38.5 ton/ha and 10,537 B/ha in SCL soil; 28.6 ton/ha and -9,912 B/ha in LS soil). The highest water use efficiency was found in the high-frequency fertigation with NB model (7.83 kg/m^3 in SCL soil and 6.52 kg/m^3 in LS soil), and the control was the lowest (3.35 kg/m^3 in SCL soil and 2.66 kg/m^3 in LS soil). The N, P and K use efficiency varied from 0.91 to 2.17 ton/kg, 1.77 to 3.66 ton/kg and 0.57 to 3.03 ton/kg in SCL soil. However they arranged from 0.48 to 0.79 ton/kg, 1.19 to 2.19 ton/kg and 0.35 to 1.11 ton/kg in LS soil. The findings of results showed that the fertilizer use efficiency responded negatively to the amount of applied fertilizers but positively to the fertigation frequency. The overall results demonstrated that the high-frequency fertigation with NB model improved the nutrient uptake and water use efficiency, increased the yield and starch content of cassava, and consequently enhanced the income of farmers.

4.2 Introduction

In recent years, food and industrial material are produced from cassava. How to increase the cassava yield has become the most crucial issue in Northeast Thailand. In the field experiment, the fertilizer and water are two essential elements in cassava production. Unsuitable fertilization will induce the pets and diseases to reduce the cassava yield. Soil fertility also can be influenced by fertilization. For example, nitrogen is an essential element most prone to leaching by the soil fertilization, with nitrate formed at the end. Reasonable fertilization should be able to bring such advantages, reduce the environment pollution, increase the yield and improve the profitability. Using the fertigation for cassava production is necessary, but it is less implemented in developing countries than in developed countries in the cultivation of field (Liang et al., 2014).

Fertigation is defined as a system in which fertilizers are injected into the water by an irrigation system. There are several advantages of fertigation for cassava, and it can improve both fertilizer and water use efficiency, and reduce the nutrient leaching and water loss. Hence fertigation cassava will produce a high yield, an excellent quality of product with less water and fertilizers. Fertigation could increase nutrient utilization via nutrient recycling within the plant, resulting in improved fertilizer use efficiency of potato (Westermann, 2005). The amount of applied fertilizer is a key for fertigation cassava. If farmers apply an excessive amount of fertilizers, or fertilizers are not soluble, it will not only damage the crop but also pollute the environment by the accumulation of salts (Landis et al., 2009). There was much information on cassava fertigation, but less attention had been paid to fertilizer formulas such as Department of Agriculture (DOA) recommendation and nutrient balance (NB) model, for cultivating cassava with fertigation. In the chapter III, the results obtained from the study had been shown that the fertigation was better than the drip irrigation with soil fertilizer application, but the performance of the two treatments was not highly significant, so the research subject of this chapter was to extend the different fertilizer formulas and fertigation frequencies for cassava production.

In this chapter, the two fertilizer formulas mentioned above were used to achieve the information collection about the plant growth parameters, leaf chlorophyll content, leaf tissue nutrient, leaf area index (LAI), crop growth rate (CGR), tuber yield and starch content, harvest index (HI), water and fertilizer use efficiency, and economic evaluation. Different frequencies of fertigation were also tested to determine the optimal fertigation frequency and fertilizer rates in cassava production.

4.3 Materials and methods

4.3.1 Experimental site description

The experiment was carried out under the field conditions in 2016 and 2017 at the Suranaree University of Technology Farm, Nakhon Ratchasima, Thailand. The experimental site is 230 m above sea level with the 14°52′ N latitude and 102°0′ E longitude. Two fields with different soil textures were used for planting cassava. One was sandy clay loam (SCL) with the bulk density 1.3 g/cm^3 and porosity 51.1%, water holding capacity 1.61-1.68 mm/cm, soil pH 6.56-6.63 and EC value 32.3-49.6 μS/cm; the other was loamy sand (LS) with the bulk density 1.4 g/cm^3 and porosity 50.1%, water holding capacity 0.95-1.02 mm/cm, soil pH 5.88-6.03 and EC value 86.4-93.6 μS/cm. Some main physical and chemical properties of soils were analyzed from the soil layer (0-30 cm) before the experiment began and were summarized in Table 4.1 and 4.2, including OM, Av.P, Ex.K, Ex.Ca and Ex.Mg. Chemical properties of the applied water were listed in Table 4.3. The high-quality irrigation water was obtained near the experimental site using a well performance water pump.

Table 4.1 Some physical and chemical properties of SCL soil (0-30 cm depth).

Physical properties			
Depth	**Bulk density**	**Porosity**	**AWHC**
	(g/cm^3)	**(%)**	**(mm/cm)**
0-15	1.3	51.1	1.61
15-30	1.3	51.1	1.68

Chemical properties							
Depth	**pH**	**EC**	**OM**	**Av.P**	**Ex.K**	**Ex.Ca**	**Ex.Mg**
		(µS/cm)	**(%)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
0-15	6.71	50.2	1.32	22.8	105.4	926.0	234.4
15-30	6.63	32.4	1.19	16.2	71.3	451.1	125.4

BD: bulk density; AWHC: available water holding capacity; EC: electric conductivity; OM: organic matter; Av.P: available P; Ex.K: exchangeable K; Ex.Ca: exchangeable Ca; Ex.Mg: exchangeable Mg.

Particle density: 2.66 g/cm^3.

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Table 4.2 Some physical and chemical properties of LS soil (0-30 cm depth).

Physical properties			
Depth	**Bulk density**	**Porosity**	**AWHC**
	(g/cm³)	**(%)**	**(mm/cm)**
0-15	1.4	50.7	0.95
15-30	1.4	50.7	1.02

Table 4.2 Continue

Chemical properties							
Depth	**pH**	**EC**	**OM**	**Av.P**	**Ex.K**	**Ex.Ca**	**Ex.Mg**
		(μS/cm)	**(%)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**	**(mg/kg)**
0-15	6.03	93.6	0.58	16.5	59.2	268.7	119.8
15-30	5.88	86.4	0.40	10.5	38.8	129.4	102.2

Particle density: 2.84 g/cm^3.

Table 4.3 Some chemical properties of the applied water for SCL soil and LS soil.

Soil texture	**pH**	**EC**	**OM**	**P**	**K**	**Ca**	**Mg**	**Fe**	**Zn**	**Cu**
		(μS/cm)	**(%)**				**(mg/L)**			
SCL	7.10	135.2	0.001	0.022	12.0	9.6	0.05	1.04	0.15	0.001
LS	6.90	153.1	0.002	0.002	2.2	10.7	1.13	0.51	0.11	0.003

4.3.2 Climatic conditions of the experimental site

The experimental site belongs to the tropical climate (Phiwngam et al., 2016), which can be divided into three seasons: rainy season (May to October), cool season (October to February) and hot season (February to May). The mean annual temperature was 27.8°C (Thai Meteorological Department, 2016) and the average annual rainfall of 1372 mm (SCL) and 1208 mm (LS), respectively, were recorded from the planting to harvesting during the trial periods in the experimental sites. During the trial years, the total frequency of rainfall was monitored, 88 times in 2016 and 90 times in 2017. The highest precipitation was 284 mm and 269 mm per month in each year.

4.3.3 Experimental design and planting method

In both soils, treatments were arranged in a randomized complete block design (RCBD) with four replications. Treatments were:

T_1: drip irrigation + no fertilizer

T_2: drip irrigation + 2 times soil fertilizer (N+P+K) application (in the 2nd and the 4th MAP) based on DOA recommendation

T_3: drip irrigation + 6 times fertigation (every two weeks) with the same amount of total nutrients of T_2

T_4: drip irrigation + 6 times fertigation (every two weeks) of N P K based on nutrient balance model

T_5: drip irrigation + fertigation (every time of watering) of N P K based on nutrient balance model

T_6: drip irrigation+2 times soil application of P (in the 2nd and the 4th MAP) and fertigation of N K (every time of watering) with the same amount of total nutrient of T_5

The planting date of cassava was from the September 2016 to January 2018. Variety of cassava and planting method were performed as same as the chapter III (section 3.3.3). All fertilizers were applied from the 2nd to 6th MAP. Pest control was carried out according to the local recommendations, and weeds were controlled manually with the hoes.

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4.3.4 Fertilizer formulas

The composition of fertilizers (soil fertilizer application and fertigation) was performed as the same as the chapter III (section 3.3.4). The amount of applied fertilizer was presented in Table 4.4 according to the DOA recommendation and NB model. The DOA recommendation was based on the soil test while the NB model was based on the nutrient balance equation (1). The amount and frequency of fertilization (soil fertilizer application and fertigation) were shown in Table 4.5 for the SCL soil and Table 4.6 for the LS soil.

$$NS = \frac{NR - (SAN - SM)}{Ue} \tag{1}$$

Where NS: nutrient supply (kg/ha), NR: nutrient requirement (kg/ha), SAN: soil available nutrient (kg/ha), SM: safe margin (kg/ha), Ue: nutrient uptake efficiency (%).

Table 4.4 Amount of fertilizers used in the experiment according to different fertilizer formulas in SCL soil and LS soil.

Fertilizer formula	SCL (kg/ha)			LS (kg/ha)		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
DOA	35	35	25	70	35	50
NB	89	25	141	128	32	176

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Table 4.5 Amount and frequency of fertilization of the treatments in SCL soil.

Treatment	Fertilization method	Frequency	N (46-0-0)	P (18-46-0)	P (12-60-0)	K (0-0-60)
		(times)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)
T 1	-	-	0	0	0	0
T 2	Soil application	2	46.3	76.1	-	41.7
T 3	Fertigation	6	60.9	-	58.3	41.7
T 4	Fertigation	6	182.3	-	41.1	234.4
T 5	Fertigation	18	182.3	-	41.1	234.4
T 6	Soil application	2	-	53.6	-	-
	Fertigation	18	182.3	-	-	234.4

Table 4.6 Amount and frequency of fertilization of the treatments in LS soil.

Treatment	Fertilization method	Frequency	N (46-0-0)	P (18-46-0)	P (12-60-0)	K (0-0-60)
		(times)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)
T 1	-	-	0	0	0	0
T 2	Soil application	2	122.4	76.1	-	83.3
T 3	Fertigation	6	137.0	-	58.3	83.3
T 4	Fertigation	6	263.8	-	53.4	293.4
T 5	Fertigation	35	263.8	-	53.4	293.4
T 6	Soil application	2	-	69.7	-	-
	Fertigation	35	263.8	-	-	293.4

4.3.5 Experimental irrigation regime

In both locations, irrigation water was applied by the drip irrigation system, which was installed before the cassava planting. The construction of drip irrigation system and the rule of irrigation applied were performed as same as the chapter III (section 3.3.5). The root depth of 10 cm and 15 cm were used to calculate the water requirement of cassava in the 1^{st} and the 2^{nd} MAP, and root depth of 30 cm was used from the 3^{rd} MAP until the harvesting (Table 4.7 and 4.8). The ETc model (Allen et al., 1998) and water balance equation were performed as same as the chapter III (section 3.3.5, equation (1) and (2)) in order to predict the amount and frequency of water supply.

Table 4.7 Water requirement of cassava in SCL soil.

Age	**ETp (mm)**	**Kc**	**ETc (mm/day)**	**Root depth (cm)**	**Root AWHC (mm)**	**Frequency (days)**	**Duration (hours)**
Sep.	3.36	0.30	1.01	10	16.5	8	1.5
Oct.	3.42	0.30	1.03	15	24.8	12	2.2
Nov.	3.51	0.60	2.11	30	49.5	12	4.5
Dec.	3.41	0.85	2.90	30	49.5	9	4.5
Jan.	3.37	1.10	3.71	30	49.5	7	4.5
Feb.	3.95	1.10	4.35	30	49.5	6	4.5
Mar.	4.39	1.10	4.83	30	49.5	5	4.5
Apr.	4.64	1.10	5.10	30	49.5	5	4.5
May.	4.20	1.10	4.62	30	49.5	5	4.5
Jun.	3.95	0.90	3.56	30	49.5	7	4.5
Jul.	3.89	0.70	2.72	30	49.5	9	4.5
Aug.	3.79	0.00	0.00	30	49.5	0	0

AWHC = 1.65 mm/cm; Drip rate = 5. 56 mm/h

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Table 4.8 Water requirement of cassava in LS soil.

Age	ETp (mm)	Kc	ETc (mm/day)	Root depth (cm)	Root AWHC (mm)	Frequency (days)	Duration (hours)
Jan.	3.37	0.30	1.01	10	10.0	5	0.8
Feb.	3.95	0.45	1.78	15	15.0	4	1.1
Mar.	4.39	0.65	2.85	30	30.0	5	2.3
Apr.	4.64	1.10	5.10	30	30.0	3	2.3
May.	4.20	1.10	4.62	30	30.0	3	2.3
Jun.	3.95	1.10	4.35	30	30.0	3	2.3
Jul.	3.89	1.10	4.28	30	30.0	4	2.3
Aug.	3.79	1.10	4.17	30	30.0	4	2.3
Sep.	3.36	0.90	3.02	30	30.0	5	2.3
Oct.	3.42	0.70	2.39	30	30.0	6	2.3
Nov.	3.51	0.50	1.76	30	30.0	9	2.3
Dec.	3.41	0.00	0.00	30	30.0	0	0

AWHC = 1.00 mm/cm; Drip rate = 6.67mm/h.

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4.3.6 Soil preparation and analysis

The soil preparation and analysis were performed as same as the chapter III (section 3.3.6).

4.3.7 Data measurement

The data of all treatments were collected from both soils of the experiment. The leaf tissue nutrient, tuber yield, tuber number, tuber starch content, water use efficiency (WUE) and fertilizer use efficiency (FUE) of cassava was performed as same as the chapter III (section 3.3.7). The plant height (from the soil surface to the leaf tip), stem diameter (main stem) and branch number were measured directly in situ from the 2nd to 6th MAP. The leaf chlorophyll content was determined using the chlorophyll meter (SPAD-502) from the 2nd to 6th MAP. The fresh weight and dry weight were measured at the 4th, 8th and 12th MAP. The leaf area was measured using the area meter (LI-3100C) at the 4th MAP, and the leaf area index (LAI) was calculated according to the equation (2). The crop growth rate (CGR) was calculated by above ground dry matter (DM) at the 4th and 8th MAP according to the equation (3). Harvest index (HI) was calculated according to the equation (4). Economic evaluation (gross income, cost and net income) was calculated after harvesting.

$$LAI = \frac{LA}{GA} \qquad (2)$$

Where LAI: leaf area index, LA: total leaf area of a plant (m^2/plant), GA: ground area occupied by the plant (m^2).

$$CGR = \frac{W2 - W1}{\rho(t2 - t1)} \qquad (3)$$

Where CGR: crop growth rate (gday/^{2}m/), W1: dry weight of whole plant recorded at time t1 (g), W2: dry weight of whole plant recorded at time t2 (g), ρ: the ground area on which W1 and W2 are recorded (m^2), t1: the recorded time of W1 (day), t2: the recorded time of W1 (day).

$$HI = \frac{Ey}{By} \times 100 \qquad (4)$$

Where HI: harvest index (%), Ey: Economic yield (ton/ha), By: biological yield (ton/ha).

4.3.8 Calculations and statistical analysis

Data were analyzed using SPSS Statistics 22 with the general linear model (Allen et al., 2014). In all analyses, mean values were compared using Ducan's multiple range tests and the significant differences were tested at P-value < 0.05.

4.4 Results and discussion

4.4.1 Plant growth parameters

The plant growth parameters including plant height, stem diameter, branch number and leaf chlorophyll content were presented in Fig 4.1 and Fig 4.2. Generally, the plant growth parameters of fertigation treatments measured from different periods were higher than soil fertilizer application treatment (T_2) in both soils. The lowest plant growth parameters were obtained from control (T_1) during the 60-180 days after planting in both soils.

In SCL soil, the plant height of T_4 (84-147 cm) was the highest and T_3 (77-134 cm) came second from 60 to 120 DAP. T_5 (168 and 187 cm) and T_6 (156 and 180 cm) exceeded T_4 (157 and 185 cm) and T_3 (149 and 174 cm) at 150 and 180 DAP, respectively (Fig 4.1-a1). The stem diameter of T_4 (13.2-20.9 mm) was the thickest from 60 to 120 DAP. T_5 (22.2 and 24.2 mm) exceeded T_4 (21.3 and 23.5 mm) at 150 and 180 DAP (Fig 4.1-a2). The branch number of T_5 (2.92-3.26 per plant) was the highest from 60 to 180 DAP, and T_4 (2.51-3.20 per plant) came second (Fig 4.1-a3). The chlorophyll content of T_4 (51.2-56.2 SPAD) was the highest from 60 to 120 DAP, and T_3 (50.3-55.7 SPAD) ranked second. T_5 (60.4 and 58.3 SPAD) exceeded T_4 (59.1 and 57.8 SPAD) at 150 and 180 DAP (Fig 4.1-a4).

In LS soil, the plant height of T_4 (75 and 105 cm) was the highest at 60 and 90 DAP, and T_5 (74 and 103 cm) came second, respectively. T_5 (130-179 cm) and T_6 (125-173 cm) exceeded T_4 (123-169 cm) from 120 to 180 DAP (Fig 4.2-b1). The stem diameter of growth trend was as same as the plant height. T_4 (11.4 and 13.7 mm) was the highest at 60 and 90 DAP, and T_5 (10.5 and 12.7 mm) came second, respectively. The treatments of high-frequency fertigation exceeded the treatments of low-frequency fertigation from 120 to 180 DAP. T_5 (15.2-20.5 mm) was the highest, and T_6 (15.1-19.2 mm) ranked second (Fig 4.2-b2). The branch number of T_5 (2.15-3.2.86 per plant) was the highest, and T_4 (2.13-2.39 per plant) came second from 60 to 180 DAP (Fig 4.2-b3). The chlorophyll content of T_5 (49.1-55.6 SPAD) was the highest from 60 to 180 DAP. T_4 (49.0 and 51.1 SPAD) came second at 60 and 120 DAP, respectively. T_6 (52.9-54.1 SPAD) exceeded T_4 (52.8-53.9 SPAD) and T_3 (51.6-52.9 SPAD) from 120 to 180 DAP (Fig 4.2-b4).

Quantized growth parameters determined tuber yield in cassava production (Streck et al., 2014). The results revealed that the fertilizer treatments of all measured periods including the soil fertilizer application and fertigation promoted the plant growth parameters in both soils. Temegne and Ngome, (2017) reported that fertilization promoted the plant growth parameters of cassava in the center region of Cameroon. In addition, the plant growth parameters of fertigation were better than soil fertilizer application in both soils. Soil fertilizer application with the large dose at the beginning period was not beneficial to maintain the nutrient absorption by cassava. This viewpoint was consistent with Darwish et al. (2004) who summarized the different K fertilization methods to the potato. Compared with the soil fertilizer application, fertigation could persistently provide the nutrients for cassava uptake, thereby enhancing the plant growth parameters. Compared with the DOA recommendation, the NB model might ensure the soil fertility and output the adequate nutrient to the aboveground part of cassava from the soil. In SCL soil, the high-frequency fertigation with NB model from 150 to 180 DAP had a rapid increase in plant height and stem diameter of cassava. However, the results measured in LS soil were from 120 to 180 DAP. These results might be due to the effects of soil properties on soil fertility and the speed of nutrient movement, which was faster in LS soil compared to SCL soil (Johnston and Bruulsema, 2014). The planting height of T_5 was higher than that reported by Silva et al. (2013) when the planting density was the same from 60 to 180 DAP. Sampathkumar and Pandian (2010) reported that high-frequency fertigation with 150 percent of RDF obtained the highest plant height of maize in sandy clay soil. The growth trend of stem diameter was as similar as the plant height. The result of stem diameter was as same as Olaiya et al. (2016) who reported that the thicker stem diameter, the taller plant height. The high-frequency fertigation with NB model increased the number of branches. Ghiyal et al. (2018) reported that high-frequency fertigation with N (120 kg/ha) got the maximum plant height and shoot number of potato in sandy loam soil. The number of branches is the critical growth parameter in many crops. Increasing the number of branches is beneficial to expose the number of leaves that accept sunlight for photosynthesis (Mathias and Kabambe, 2015). The trend of chlorophyll content was increasing from 60 to 150 DAP but had a decrease trend at 180 DAP. Santos et al. (2013) indicated that the chlorophyll content of cassava was changing with age and decreased with the plant maturity. Fertigation could improve the chlorophyll content of crops compared to the traditional fertilizer application (Jeelani et al., 2017). Ewais et al. (2010) also reported that fertigation with N (120 kg/fed) increased the chlorophyll content of onion compared to the soil fertilizer application in sandy soil.

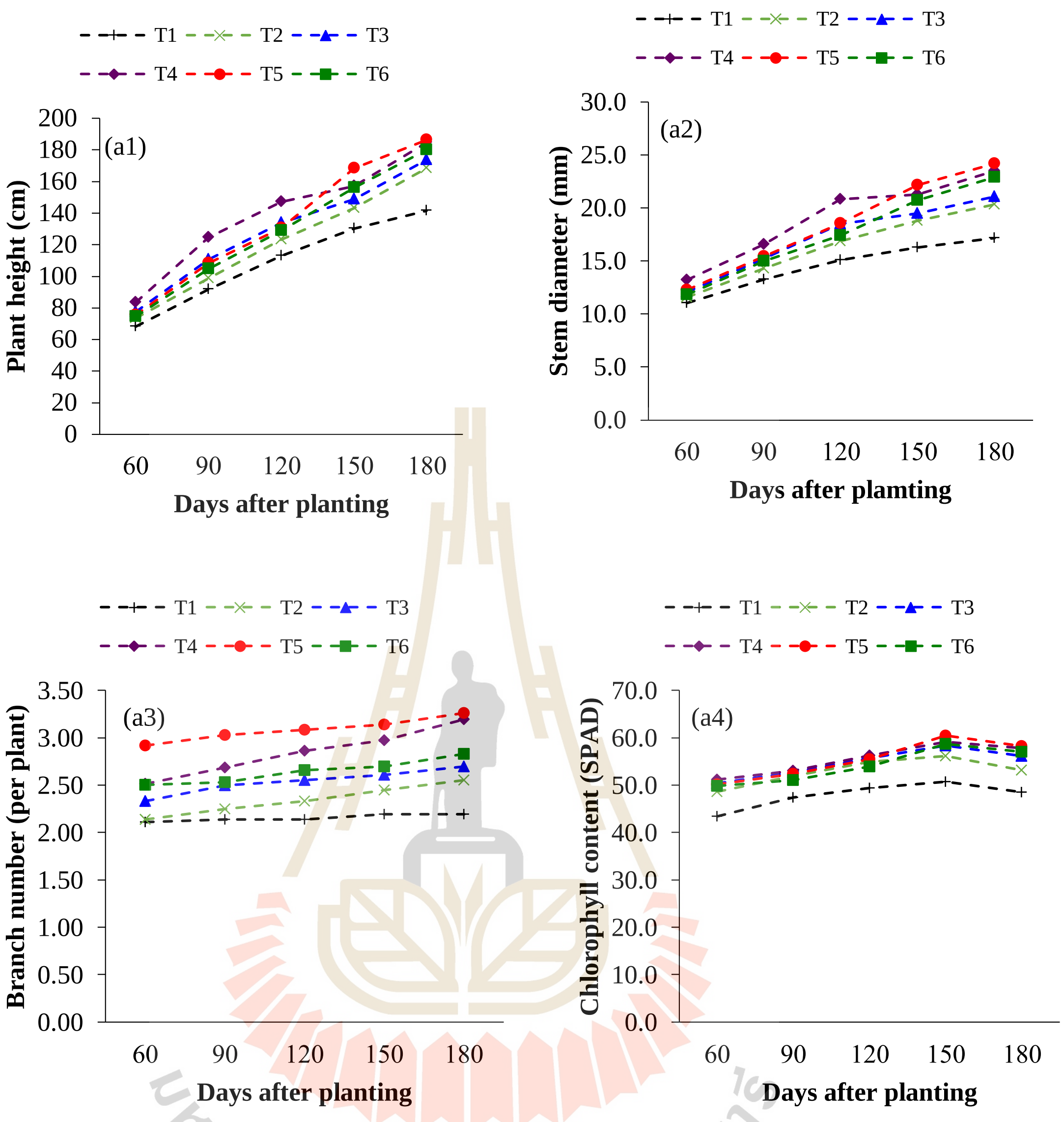

Fig 4.1 Plant growth parameters of different treatments measured at 60 90 120 150 and 180 DAP in SCL soil (a1-a4).

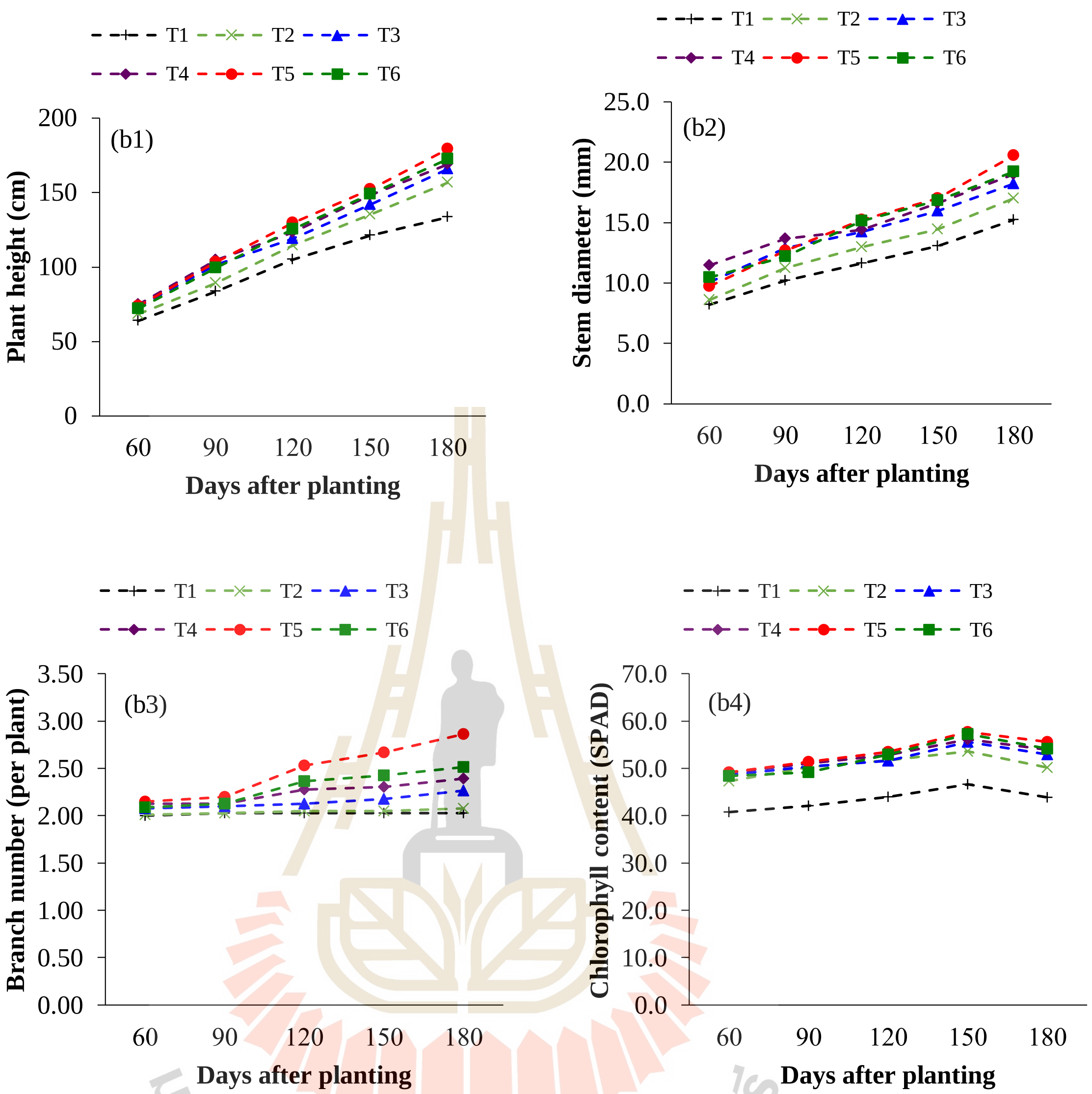

Fig 4.2 Plant growth parameters of different treatments measured at 60 90 120 150 and 180 DAP in LS soil (b1-b4).

4.4.2 LAI and CGR of cassava

The LAI of cassava was measured at the 4th MAP in both soils. The results in Fig 4.3-c1 showed that T_4 (2.36) had significantly higher LAI than other treatments in SCL soil, and T_1 (0.45) was the lowest. The difference in LAI between T_3 (1.89) and T_5 (1.87) was not significant, but they significantly differed from T_6 (1.59), which was significantly higher than T_2 (1.33). However, in LS soil (Fig 4.3-c2), the highest and the lowest LAI were observed from the T_5 (1.85) and T_1 (0.25), respectively. The difference in LAI between T_4 (1.43) and T_6 (1.38) was not significant, but they significantly differed from T_3 (1.24), which was significantly higher than T_2 (0.68). The higher LAI might be due to the more number of leaves, which were produced by the increasing photosynthetic area of cassava (Rajput et al., 2017). Fertigation increased the LAI of cassava compared to irrigation with conventional fertilization at 120 DAP in LS soil, which was reported by Anan and Mallika (2017) in Northeast Thailand. In the early stage of cassava growth in SCL soil, the low-frequency fertigation with NB model might supply the adequate nutrient to the soil. However, in LS soil, the high-frequency fertigation with NB model dominated the LAI due to the low volume of fertigation, which reduced fertilizer loss. Amala and Syriac (2016) reported that the higher LAI of tomato was recorded from the high-frequency fertigation (4 days interval) in sandy loam soil.

The CGR of cassava was measured at the 4^{th} and 8^{th} MAP in both soils. In SCL soil (Fig 4.4-d1), the CGR of T_5 (22.3 g/m^2/day) was significantly higher than other treatments at the 4^{th} MAP. The difference in CGR between T_4 (17.4 g/m^2/day) and T_6 (16.6 g/m^2/day) was not significant, but they significantly differed from T_3 (13.9 g/m^2/day), which was significantly higher than T_2 (11.3 g/m^2/day). T_1 (8.1 g/m^2/day) was the lowest among treatments. However, there were no significant differences among T_5 (16.2 g/m^2/day), T_4 (15.0 g/m^2/day) and T_6 (14.7 g/m^2/day) at the 8^{th} MAP, but they significantly differed from T_3 (12.9 g/m^2/day), which was significantly higher than T_2 (9.3 g/m^2/day). T_1 (5.2 g/m^2/day) was the lowest among treatments. In LS soil (Fig 4.4-d2), The differences among treatments were significant at the 4th MAP. The CGR of T_5 (15.3 g/m^2/day) was the highest, and T_6 (14.0 g/m^2/day) came second, whereas T_1 (3.2 g/m^2/day) was the lowest. However, T_5 (15.8 g/m^2/day) had significantly higher CGR than other treatments, and T_1 (5.0 g/m^2/day) was the lowest at the 8th MAP. The difference in CGR between T_4 (15.0 g/m^2/day) and T_6 (14.4 g/m^2/day) was not significant, but they significantly differed from T_3 (12.0 g/m^2/day), which was significantly higher than T_2 (7.7 g/m^2/day). The results indicated that the high-frequency fertigation with NB model enhanced the CGR due to the more fertilizer application, which increased the dry weight of cassava. The trend of CGR was a decline from the 8th MAP to the harvesting in SCL soil but increased in LS soil. When ETc was at same level, 125% RDF increased more CGR of rice than 100% and 75% RDF (Ramadass and Ramanathan, 2017). Mohan et al. (2018) also reported that the higher CGR of maize was observed in drip fertigation with the 125% RDF compared to the 100% RDF.

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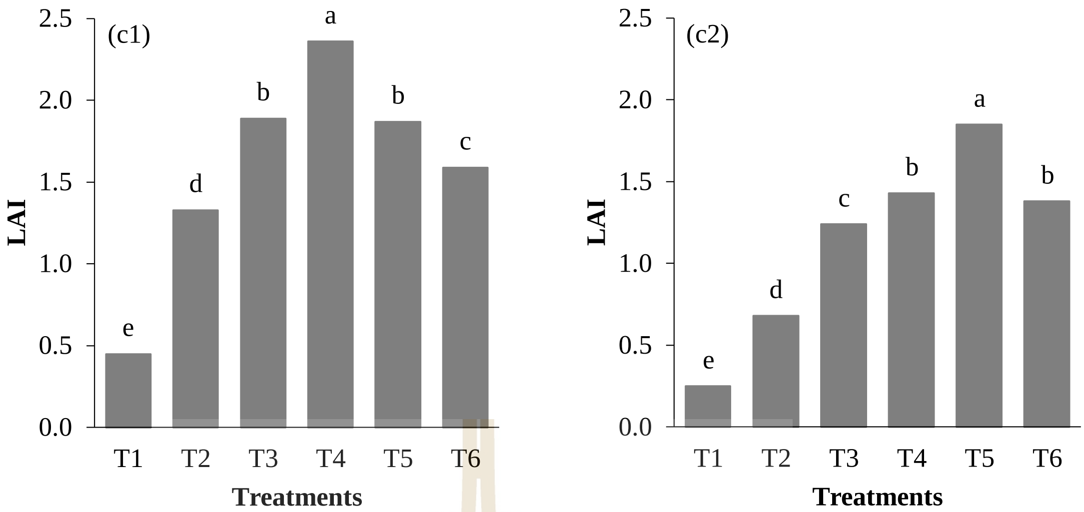

Fig 4.3 LAI of different treatments at the 4th MAP in SCL soil (c1) and LS soil (c2). Means in the same columns followed by the different letters indicate statistically significant differences as according to Duncan's multiple range test at P < 0.05.

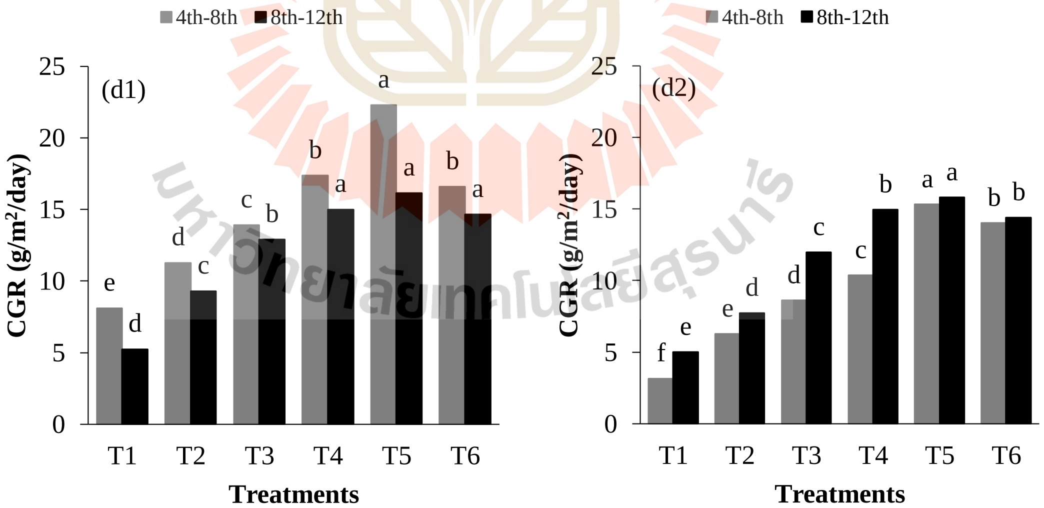

Fig 4.4 CGR of different treatments at the 4th and 8th MAP in SCL soil (d1) and LS soil (d2). Means in the same columns followed by the different letters indicate statistically significant differences as according to Duncan's multiple range test at P < 0.05.

4.4.3 Fresh weight (FW) and dry weight (DW) of cassava

The fresh weight and dry weight including leaf, stem and tuber were measured at 120, 240 and 360 DAP. In SCL soil, the results in Fig 4.5-e1 and 4.5-e2 showed that the FW and DW of leaf of T_4 (545 and 136 g/plant) were the highest at 120 DAP, whereas T_1 (234 and 48 g/plant) were the lowest. The DW of leaf of T_4 was no significant difference compared with T_3 (130 g/plant). Furthermore, the FW and DW of leaf of T_5 (1191 and 403 g/plant at 240 DAP; 419 and 189 g/plant at 360 DAP) were significantly higher than other treatments, and T_4 (1019 and 331 g/plant at 240 DAP; 363 and 156 g/plant at 360 DAP) came second, while T_1 (358 and 97 g/plant at 240 DAP; 154 and 61 g/plant at 360 DAP) were the lowest. The results in Fig 4.5-e3 and 4.5-e4 showed that the FW and DW of stem of T_4 (440 and 217 g/plant) were significantly higher than other treatments at 120 DAP, whereas T_1 (236 and 71 g/plant) were the lowest. The FW of stem of T_4 was no significant difference compared with T_5 (431 g/plant). Furthermore, The FW and DW of stem of T_5 (2203 and 794 g/plant at 240 DAP; 3009 and 1000 g/plant at 360 DAP) were significantly higher than other treatments, and T_1 (613 and 183 g/plant at 240 DAP; 1868 and 531 g/plant 360 DAP) were the lowest. The results in Fig 4.5-e5 and 4.5-e6 showed that the FW and DW of tuber of T_4 (807 and 271 g/plant) were significantly higher than other treatments at 120 DAP, whereas T_1 (323 and 74 g/plant) were the lowest. Furthermore, the FW and DW of tuber of T_5 (4841 and 1855 g/plant at 240 DAP; 8651 and 3941 g/plant at 360 DAP) were the highest, whereas T_1 (2568 and 847 g/plant at 240 DAP; 3700 and 1210 g/plant at 360 DAP) were the lowest ($P < 0.05$).

However, in LS soil, the results in Fig 4.6-f1 and 4.6-f2 showed that the FW and DW of leaf of T_5 (535 and 108 g/plant) were significantly higher than other treatments at 120 DAP, while T_1 (140 and 16 g/plant) were the lowest. Furthermore, The FW and DW of leaf of T_5 (991 and 286 g/plant at 240 DAP; 289 and 109 g/plant at 360 DAP) were significantly higher and than other treatments but no significant different from T_6 (969 and 274 g/plant at 240 DAP; 280 and 103 g/plant at 360 DAP), while T_1 (278 and 136 g/plant at 240 DAP; 69 and 46 g/plant at 360 DAP) were the lowest. The results in Fig 4.6-f3 and 4.6-f4 showed that the FW and DW of stem of T_5 (419 and 165 g/plant) were significantly higher than other treatments at 120 DAP, while T_1 (144 and 39 g/plant) were the lowest. Furthermore, The FW of stem of T_5 (2001 g/plant at 240 DAP; 2640 g/plant at 360 DAP) was significantly higher than other treatments but no significant different from T_6 (1861 g/plant at 240 DAP; 2574 g/plant at 360 DAP), while the DW of stem of T_5 (696 g/plant at 240 DAP; 866 g/plant at 360 DAP) was the highest, T_6 (625 g/plant at 240 DAP; 816 g/plant at 360 DAP) ranked second. While T_1 (524 and 142 g/plant at 240 DAP; 1566 and 410 g/plant at 360 DAP) were the lowest. The results in Fig 4.6-f5 and 4.6-f6 showed that the FW and DW of tuber of T_5 (612 and 170 g/plant) were significantly higher than other treatments at 120 DAP, while T_1 (188 and 40 g/plant) were the lowest. Furthermore, the FW and DW of tuber of T_5 (3771 and 1436 g/plant) were the highest at 240 DAP, and T_6 (3461 and 1248 g/plant) joined second, whereas T_1 (1001 and 291 g/plant) were the lowest. T_5 (6736 g/plant) had significantly higher FW of tuber than other treatments but no significant difference from T_6 (6462 g/plant) at 360 DAP, while T_1 (2744 g/plant) was the lowest. DW of tuber of T_5 (3263 g/plant) was the highest, and T_6 (2888 g/plant) joined second, whereas T_1 (620 g/plant) was the lowest ($P < 0.05$).

Low-frequency fertigation with NB model in SCL soil and high-frequency fertigation with NB model in LS produced the higher FW and DW of cassava at 120 DAP. However, the higher FW and DW of cassava were consistently obtained by the high-frequency fertigation with NB model in both soils at the 240 and 360 DAP. At 120 DAP, the low-frequency fertigation was more suitable in SCL soil compared to LS soil, but the high-frequency fertigation was conducive to the long-term cassava production. The results might be due to the NB model, which increased nutrient absorption of cassava. Overall results of this study were in agreement with most research finding in cassava and other crops. The results were same as the viewpoint of Howeler (1985) who summarized that the higher nutrient concentrations accumulated in the roots as well as in the leaf and stem. Silber et al. (2003) reported that the high-frequency fertigation could compensate for the nutrient deficiency and increase the FW and DW of lettuce. Melgar et al. (2010) reported that the DW of the citrus leaf and stem were unaffected by the frequency of fertigation, but daily fertigation was higher than fertigation of every three days and two weeks, and the total DW of roots was the highest with the daily fertigation.

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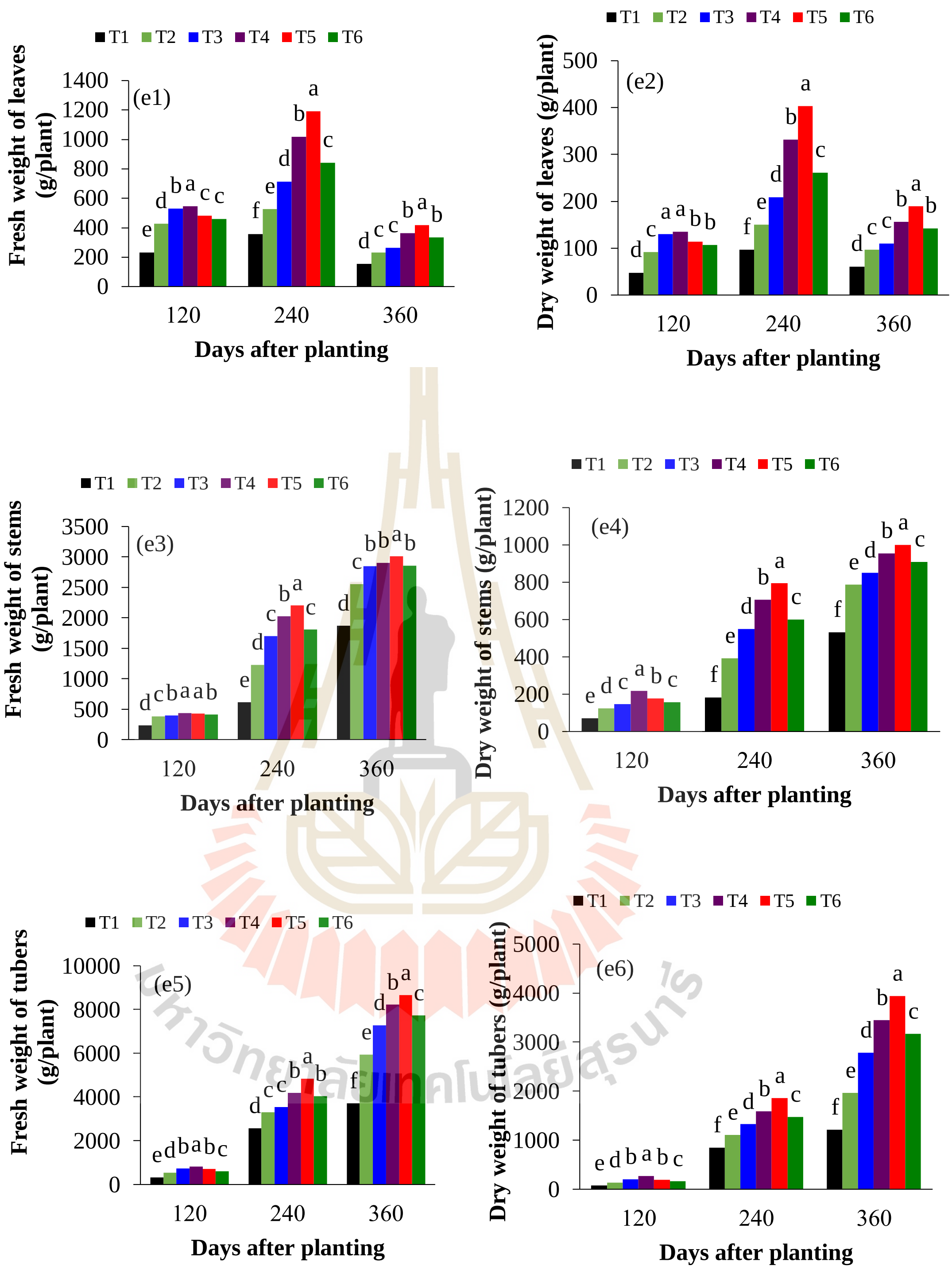

Fig 4.5 Leaf, stem and tuber fresh weight and dry weight of different treatments at the 120, 240 and 360 DAP in SCL soil. Means in the same columns followed by the different letters indicate statistically significant differences as according to Duncan's multiple range test at $P < 0.05$.

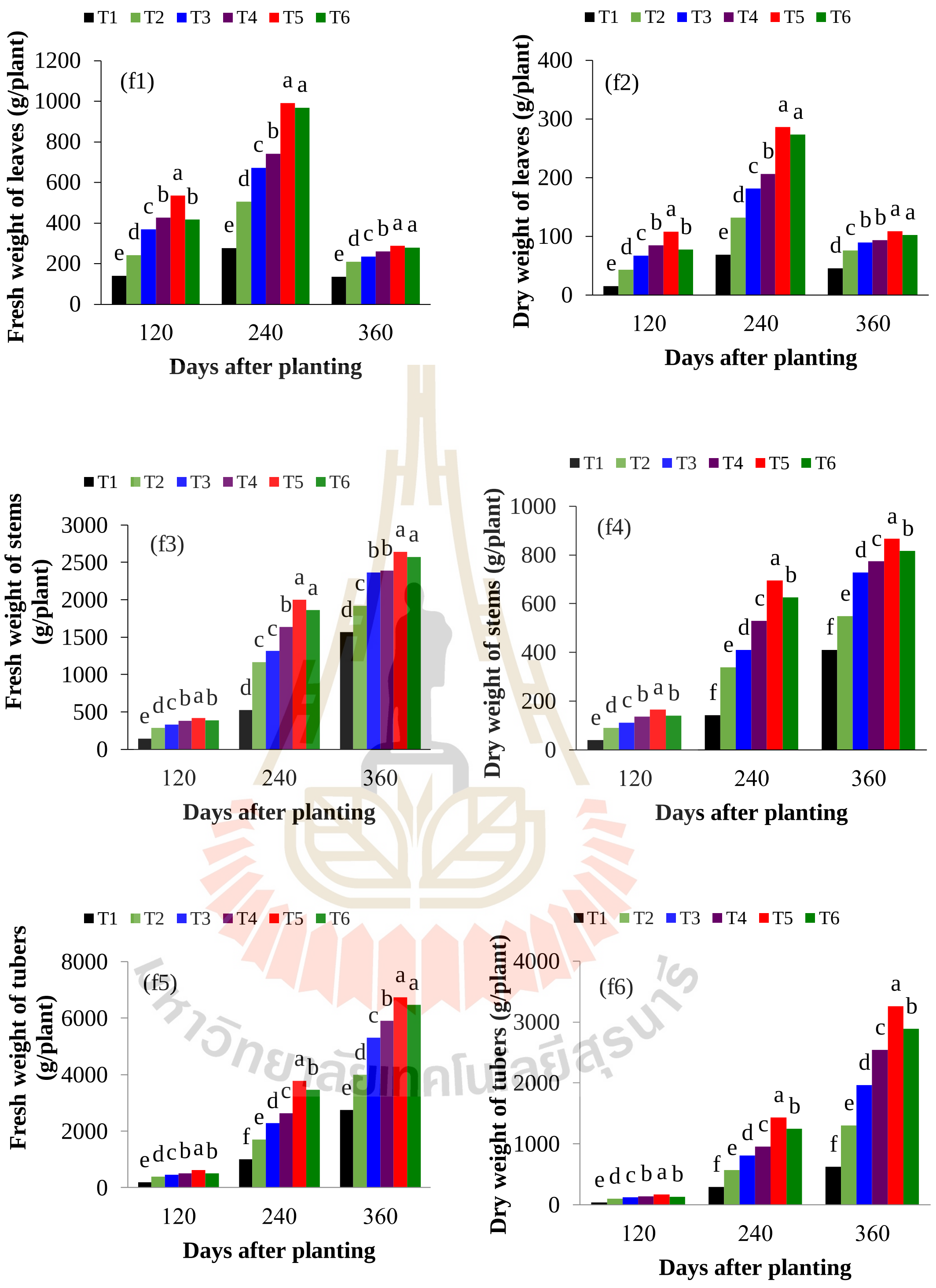

Fig 4.6 Leaf, stem and tuber fresh weight and dry weight of different treatments at the 120, 240 and 360 DAP in LS soil. Means in the same columns followed by the different letters indicate statistically significant differences as according to Duncan's multiple range test at P < 0.05.

4.4.4 Leaf tissue nutrient of cassava

Table 4.9 and 4.10 presented the leaf tissue nutrient of different treatments at the 4th MAP in two textured soils. In SCL soil, the results in Table 4.9 showed that the N content of T_4 (5.77%) was significantly different from other treatments. The differences in N content among T_3 (5.49%), T_5 (5.45%) and T_6 (5.34%) were not significant, but they significantly differed from T_2 (5.05%). The N content of T_1 (4.00%) was the lowest. The P content of T_4 (0.37%) was significantly higher than other treatments. There were no significant differences among T_3 (0.29%), T_5 (0.28%), T_6 (0.28%) and T_2 (0.27%), but they were significant higher than T_1 (0.21%), which was the lowest. The K content of T_4 (1.55%) was significantly different from other treatments but was no significant difference compared with T_5 (1.48%) and T_6 (1.44%). The difference in K content between T_3 (1.50%) and T_2 (1.25%) was not significant, but they were significantly higher than T_1 (1.00%). However, in LS soil, Table 4.10 showed that T_5 (4.82%) had significantly higher N content than other treatments but did not significantly differ from T_4 (4.66%). No significant differences in N content were found among T_6 (4.45%), T_3 (4.43%) and T_2 (4.38%), and T_1 (3.16%) was the lowest among treatments. The P content of T_5 (0.27%), T_6 (0.27%), T_4 (0.26%) and T_3 (0.26%) that didn't have significant differences were significantly higher than T_2 (0.22%). The P content of T_1 (0.20%) was the lowest. The K content of T_5 (1.45%) was significantly higher than other treatments, and T_1 (0.61%) was the lowest ($P < 0.05$).

Comparing the N, P and K content with the sufficient level, the results in Table 4.9 showed that T_1 and T_2 presented N and K deficiency, but T_3 T_4 T_5 and T_6 manifested N and K content sufficiency, and all treatments presented P content deficiency in SCL soil. However, In Table 4.10, all treatments presented N and P content deficiency, and K content was deficiency except T_5 in LS soil. The results indicated that the NB model fertigation improved the uptake of nutrients from the soils. The performances of NB model in two textured soils were different because of the capacity of holding fertilizers. The results were supported by the other researches such as Tahir and Marschner (2017) who reported that adding the clay soil to the sandy soil could substantially reduce the N and P fertilizer leaching and increased the fertilizer retention compared to the single sandy soil. The high-frequency fertigation with NB model could enhance the concentration of nutrients, and the increased frequencies of fertigation continuously replenished the nutrients to the root zone of cassava in the LS soil. Kachwaya and Chandel (2015) reported that the different recommended doses of NPK fertigation had higher leaf nutrient contents of strawberry compared to soil fertilization. The same result was reported by Jeyakumar et al. (2008) and showed that papaya fertigation (different levels of N and K_2O) was higher in leaf nutrient contents compared to the soil fertilization.

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Table 4.9 Leaf tissue nutrient in the 4th MAP of different treatments in SCL soil.

Treatment	N (%)	P (%)	K (%)
T1	4.00d	0.21c	1.00c
T2	5.05c	0.27b	1.25b
T3	5.49b	0.29b	1.50b
T4	5.77a	0.37a	1.55a
T5	5.45b	0.28b	1.48a
T6	5.34b	0.28b	1.44a
Sufficient level (%)	5.10	0.38	1.42
C.V. (%)	5.0	2.2	4.4

Means in the same columns followed by the different letters indicate statistically significant differences as according to Duncan's multiple range test at $P < 0.05$.

Table 4.10 Leaf tissue nutrient in the 4th MAP of different treatments in LS soil.

Treatment	N (%)	P (%)	K (%)
T1	3.16c	0.20b	0.62d
T2	4.38b	0.22b	1.02c
T3	4.43b	0.26a	1.06c
T4	4.66a	0.26a	1.24b
T5	4.82a	0.27a	1.45a
T6	4.45b	0.27a	1.21b
Sufficient level (%)	5.10	0.38	1.42
C.V. (%)	5.5	1.5	6.5

Means in the same columns followed by the different letters indicate statistically significant differences as according to Duncan's multiple range test at $P < 0.05$.

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4.4.5 Tuber number, starch content, yield and HI of cassava

The tuber number, yield and starch content of cassava were obtained at harvesting in both soils. The results in Table 4.11 showed that the tuber number varied from 8.8 to 18.9 per plant in SCL soil. T_5 had significantly higher tuber number than other treatments except T_4 (18.0 per plant), and T_1 was the lowest. The difference in the tuber number between T_3 (15.1 per plant) and T_6 (15.0 per plant) was not significant, but they were significantly higher than T_2 (11.5 per plant). In Table 4.12, the values varied from 6.9 to 9.8 per plant in LS soil. The highest tuber number was obtained from T_5, which was no significant difference compared with T_6 (9.7 per plant) and T_4 (9.7 per plant). T_1 was the lowest tuber number ($P < 0.05$). The results indicated that the higher tuber number per plant was obtained through the NB model. The reason might be due to the improving nutrient uptake of cassava. Tuber number could be influenced by phosphate (Jenkins and Ali, 2000) and potassium (Gajek, 1971) in potato production. Sangakkara and Wijesinghe (2014) reported that the different rates of N fertilizer affected tuber number per plant of cassava.

In table 4.11, the tuber starch content of T_5 (29.8%) was the highest in SCL soil but was no significant difference from T_4 (29.6%) and T_1 (26.3%) was the lowest. However, in table 4.12, the tuber starch content of T_5 (29.1%) was significantly different from other treatments in LS soil but was no significant difference compared with T_6 (28.8%), and T_1 (25.3%) was the lowest ($P < 0.05$). The results indicated that the NB model improved the uptake of K fertilizer. K played an important role on carbohydrates translocation in the cassava. Malavolta et al. (1955) demonstrated that starch content obtained from the K-sufficient plants was higher than the K-deficient plants. The application of K fertilizer improved the starch content and quality of tuber

(Nair and Aiyer, 1986; Imas and John, 2013). Cuvaca et al. (2015) reported that the combination of N, P and K fertilizer rate could affect the tuber starch content of cassava, and no significant differences of the hydrogen cyanide concentration was observed in the tubers when the addition N, P and K fertilizers were supplied.

In Table 4.11, the yield varied from 38.5 to 90.1 ton/ha in SCL soil and the differences of treatments were significant at harvesting. The yield of T_5 was the highest, and T_4 (85.6 ton/ha) came second, whereas T_1 was the lowest. However, in Table 4.12, the values varied from 28.6 to 70.2 ton/ha in LS soil. T_5 had significantly higher yield than other treatments but no significant difference from T_6 (67.3 ton/ha). The differences in yield among T_4 (61.4 ton/ha), T_3 (55.3 ton/ha) and T_2 (41.6 ton/ha) were significant at harvesting, and T_1 was the lowest among treatments ($P < 0.05$). The high-frequency fertigation with NB model enhanced the yield of cassava by several reasons. One possible explanation was that fertigation reduced the loss of fertilizers and maintained the nutrient close to the rhizosphere. Román-Paoli and Sotomayor-Ramírez (2006) reported that the cassava yield of fertigation increased by 28.5% compared to conventional fertilization with the same amount of fertilizers (275-50-250-60 kg/ha of N, P_2O_5, K_2O and MgO). The other explanation might be that the high-frequency fertigation continued to provide nutrition to the cassava when the nutrient gradually decreased in the soils. Silber et al. (2003) concluded that increasing yield was mainly related to the increase in nutrient uptake and summarized that the high-frequency fertigation could compensate for the yield reduction caused by the nutrient deficiency. The third explanation could be that the NB model balanced the nutrients, especially the secondary nutrient and micronutrient compared to the DOA recommendation. An unbalanced application of fertilizer might lead to some kind of nutrient deficiency, resulting in the reduction of cassava yield. Increasing application of K fertilizer decreased concentration of Ca and Mg, especially resulting in the Mg deficiency (Spear et al., 1978). High K fertilizer supply induced S deficiency (Ngongi et al., 1977). High rates of P fertilizer supply caused Zn deficiency (Nair et al., 1988).

In Table 4.11, the HI varied from 64.7 to 71.6% in SCL soil. T_5 had significantly HI than other treatments but did not significantly differ from T_4 (71.6%), and T_1 was the lowest. The difference in HI between T_6 (70.6%) and T_3 (70.1%) was not significant, but they were significantly higher than T_2 (68.0%). However, in Table 4.12, the values varied from 61.6 to 69.7% in LS soil. The highest HI was obtained from T_5, which was significantly different from other treatments but was no significant difference compared with T_6 (69.3%) and T_4 (69.0%). The difference between T_3 (67.1%) and T_2 (65.2%) was significant at harvesting, and they were significantly higher than T_1, which was the lowest among treatments ($P< 0.05$). The high-frequency fertigation with NB model achieving the higher HI than the other treatments (DOA recommendation, soil fertilizer application and no fertilizer) was perhaps due to the balanced nutrients absorbed by cassava root, which was more than they lost in the soil. Positive NB model was able to produce higher yield and HI, but negative NB model might reduce HI. Omondi et al. (2018) reported that increasing the fertilizer concentration of fertigation caused a decline in harvest index of cassava, sometimes luxuriously supplying nutrition was not good for cassava growth. Mazurczyk et al. (2009) also had the same report about the effect of fertilizer amount on the HI of potato.

Table 4.11 Tuber number, starch content, yield and HI of different treatments at harvesting in SCL soil.

Treatment	Tuber number (per plant)	Starch (%)	Yield (ton/ha)	HI (%)
T1	8.8d	26.3d	38.5f	64.7d
T2	11.5c	27.6c	61.8e	68.0c
T3	15.1b	28.3b	75.9d	70.1b
T4	18.0a	29.6a	85.6b	71.6a
T5	18.9a	29.8a	90.1a	71.6a
T6	15.0b	28.9b	80.4c	70.7b
C.V. (%)	10.9	4.5	7.0	3.7

Means in the same columns followed by the different letters indicate statistically significant differences as according to Duncan's multiple range test at $P < 0.05$.

Table 4.12 Tuber number, starch content, yield and HI of different treatments at harvesting in LS soil.

Treatment	Tuber number (per plant)	Starch (%)	Yield (ton/ha)	HI (%)
T1	6.9c	25.3c	28.6e	61.6d
T2	8.0b	27.3b	41.6d	65.2c
T3	8.6b	27.9b	55.3c	67.1b
T4	9.7a	27.9b	61.4b	69.0a
T5	9.8a	29.1a	70.2a	69.7a
T6	9.7a	28.8a	67.3a	69.3a
C.V. (%)	6.5	4.8	8.2	4.6

Means in the same columns followed by the different letters indicate statistically significant differences as according to Duncan's multiple range test at $P < 0.05$.

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4.4.6 Gross income, cost and net income of cassava

The total cost was calculated from the sum of labor, cassava stalk, fertilizer, irrigation system, harvesting, and land rent in each treatment. The results in Table 4.13 showed that the gross income varied from 91,674 to 233,191 B/ha in SCL soil and the difference among treatments was significant at harvesting. The gross income of T_5 was the highest, and T_4 (220,226 B/ha) came second, whereas T_1 was the lowest. In Table 4.14, the values varied from 66,256 to 178,542 B/ha in LS soil. T_5 had significantly higher gross income than other treatments but no significant difference from T_6 (170,006 B/ha). The significant differences were found among T_4 (152,109 B/ha), T_3 (136,552 B/ha) and T_2 (101,587 B/ha) at harvesting. T_1 was the lowest among treatments ($P < 0.05$).

In Table 4.13, the net income varied from 10,537 to 117,747 B/ha in SCL soil. T_5 had significantly higher net income than other treatments, followed by T_4 (107,039 B/ha). T_1 produced the lowest net income among treatments. However, in Table 4.14, the net income of T_5 (70,386 B/ha) was significantly higher than other treatments in LS soil but was no significant difference from T_6 (62,350 B/ha). The net income of T_1 (-9,912 B/ha) was the lowest ($P < 0.05$). The yield and starch content of cassava were positively correlated with the gross income and net income. Despite the high cost of fertigation, the results indicated that it increased the gross income and net income. The gross income and net income in this study were relatively high compared to the other studies of cassava. Howeler (2006) summarized that gross income, cost and net income were 13,215, 12,643 and 572 B/ha (USD exchange rate of 37.0) during the 1999-2000 in Thailand, respectively. It was also higher than Poramacom et al. (2013) reported that gross income, cost and net income were 31,549, 28,861 and 2,688 B/ha (USD exchange rate of 31.7) in 2010 in Thailand, respectively.

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Table 4.13 Gross income, cost and net income of different treatments at harvesting in SCL soil.

Treatment	GI	Cost (B/ha)						NI
	(B/ha)	Labor	Stalk	Fertilizer	IS	Harvest	LR	(B/ha)
T1	91,674f	18,125	3,125	0	31,250	19,263	9,375	10,537e
T2	151,901e	18,125	3,125	5,600	31,250	30,925	9,375	53,501d
T3	189,469d	18,125	3,125	4,763	31,250	37,931	9,375	84,900c
T4	220,226b	18,125	3,125	8,513	31,250	42,800	9,375	107,039b
T5	233,191a	18,125	3,125	8,513	31,250	45,056	9,375	117,747a
T6	203,738c	18,125	3,125	9,225	31,250	40,219	9,375	92,419c
C.V. (%)	2.6							5.8

Means in the same columns followed by the different letters indicate statistically significant differences as according to Duncan's multiple range test at $P < 0.05$.
GI: gross income; IS: irrigation system; LR: land rent; NI: net income.

Table 4.14 Gross income, cost and net income of different treatments at harvesting in LS soil.

Treatment	GI	Cost (B/ha)						NI
	(B/ha)	Labor	Stalk	Fertilizer	IS	Harvest	LR	(B/ha)
T1	66,256e	18,125	3,125	0	31,250	14,294	9,375	-9,912d
T2	101,587d	18,125	3,125	7,219	31,250	20,819	9,375	11,674c
T3	136,552c	18,125	3,125	6,388	31,250	27,631	9,375	40,658b
T4	152,109b	18,125	3,125	11,200	31,250	30,725	9,375	48,309b
T5	178,542a	18,125	3,125	11,200	31,250	35,081	9,375	70,386a
T6	170,006a	18,125	3,125	12,125	31,250	33,656	9,375	62,350a
C.V. (%)	3.5							9.6

Means in the same columns followed by the different letters indicate statistically significant differences as according to Duncan's multiple range test at $P < 0.05$.

4.4.7 Water and fertilizer use efficiency

The water use efficiency (WUE) and fertilizer use efficiency (FUE) of different treatments were listed in Table 4.15 and 4.16. The results in Table 4.15 showed that the WUE varied from 3.35 to 7.83 kg/m^3 in SCL soil and the difference among treatments was significant. The WUE of T_5 was the highest, and T_4 (7.44 kg/m^3) came second, whereas T_1 was the lowest. In Table 4.16, the values varied from 2.66 to 6.52 kg/m^3 in LS soil. T_5 had significantly higher WUE than other treatments but no significant difference from T_6 (6.26 kg/m^3). T_1 was the lowest among treatments ($P < 0.05$). The enhancement of WUE was due to the increased cassava yield by fertigation. Janat and Somi (2002) reported that drip N fertigation (60 120 180 and 240 kg/ha) obtained higher WUE compared to fertigation (0 kg/ha) by the cotton in the clayey soil. However, the results of Table 4.15 were different from EL Moujabber et al. (2002) reported that the higher WUE of cucumber was obtained from the low-frequency fertigation.

The FUE consisted of N, P and K use efficiency, which abbreviated as NUE, PUE and KUE. In Table 4.15, the NUE and KUE of T_3 (2.17 and 3.03 ton/kg) were the highest than other treatments in SCL soil, and T_6 (0.91 and 0.57 ton/kg) were the lowest. However, in Table 4.16, the NUE and KUE of T_3 (0.79 and 1.11 ton/kg) were the highest than other treatments in LS soil, and T_4 (0.53 and 0.38 ton/kg) were the lowest. The NUE and KUE calculated by the DOA recommendation (T_2 and T_3) were significant higher than by the NB model (T_4 T_5 and T_6) in both soils, but the PUE was opposite result. The PUE of T_5 (3.66 ton/kg in SCL soil and 2.19 ton/kg in LS soil) was the highest than other treatments, and T_2 (1.77 ton/kg in SCL soil and 1.19 ton/kg in LS soil) was the lowest in both soils ($P < 0.05$). The results indicated that the increased FUE of crop responded negatively to the amount of fertilizer and positively to the high-frequency fertigation with NB model. Mohammad et al. (2002) reported that the increasing rates of fertilizers in the fertigation resulted in the decrease in FUE. Darwish et al. (2002) reported that the NUE of potato was higher by reducing the rates of N. Atallah et al. (2002) reported that NUE was improved by high-frequency fertigation on the cucumber and tomato.

Overall results of the study revealed that the increased yield of cassava depended on the appropriate amount of fertilizers and optimal frequency through fertigation. If the balance for a particular nutrient is positive, the nutrient will accumulate in the soil and be absorbed by the crop. In contrast, if the balance is negative depletion, and the soil's fertility status may deteriorate. Hence, it is important not only to apply the adequate amount of fertilizers but also the correct balance among the various nutrients.

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Table 4.15 Water and fertilizer use efficiency of different treatments in SCL soil.

Treatment	**WUE (kg/m^3)**	**FUE (ton/kg)**		
		N	**P_2O_5**	**K_2O**
T1	3.35f	-	-	-
T2	5.37e	1.77b	1.77e	2.47b
T3	6.59d	2.17a	2.17d	3.03a
T4	7.44b	0.96c	3.48b	0.61c
T5	7.83a	1.02c	3.66a	0.64c
T6	6.99c	0.91d	3.27c	0.57c
C.V. (%)	11.5	10.8	10.4	9.9

Means in the same columns followed by the different letters indicate statistically significant differences as according to Duncan's multiple range test at $P < 0.05$.

Table 4.16 Water and fertilizer use efficiency of different treatments in LS soil.

Treatment	**WUE (kg/m^3)**	**FUE (ton/kg)**		
		N	**P_2O_5**	**K_2O**
T1	2.66e	-	-	-
T2	3.87d	0.59b	1.19d	0.83b
T3	5.14c	0.79a	1.58c	1.11a
T4	5.71b	0.48d	1.92b	0.35d
T5	6.52a	0.55c	2.19a	0.40c
T6	6.26a	0.53c	2.10a	0.38c
C.V. (%)	12.3	3.4	7.0	9.5

Means in the same columns followed by the different letters indicate statistically significant differences as according to Duncan's multiple range test at $P < 0.05$.

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4.5 Conclusion

The results of this research confirmed that the low-frequency fertigation with NB model affected the growth parameters, fresh and dry weight, LAI and leaf tissue nutrient at 120 DAP in SCL soil. After the 120 DAP, the high-frequency fertigation with NB model dominated the results in cassava production, and it also enhanced the net income in both soils. In this study, it revealed that the tuber yield of cassava was enhanced, the tuber starch content was increased, and the water and fertilizer use efficiency were improved by the high-frequency fertigation with NB model in Northeast Thailand. Furthermore, in this region where water is very scarce, the drip fertigation could be applied for higher tuber yield, tuber starch content, and water and fertilizer efficiency compared to the soil fertilizer application. Compared to the drip irrigation with no fertilizer treatment T_2 T_3 T_4 T_5 and T_6 were able to obtain the increasing rate of tuber yield, up to 60.5% 97.1% 122.3% 134.0% and 108.8% in SCL soil, 45.5% 93.4% 114.7% 145.5% and 135.3% in SL soil, respectively. The increasing rate of tuber starch content were 4.9% 7.6% 12.5% 13.3% and 9.9% in SCL soil, 7.9% 10.3% 10.3% 15.0% and 13.8% in LS soil, respectively. As a result, the higher yield and quality of cassava should be obtained through the high-frequency fertigation with NB model under the tropical climatic. The suitable fertigation program can be used as a suggestion to the farmers and help them to increase the income in Northeast Thailand.

4.6 References

Allen, P., Bennett, K., & Heritage, B. (2014). SPSS statistics version 22: **A practical guide**. Cengage Learning Australia.

มหาวิทยาลัยเทคโนโลยีสุรนารี

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). FAO Irrigation and drainage paper No. 56. Rome: **Food and Agriculture Organization of the United Nations**. 56(97): e156.

Amala, J., & Syriac, E. K. (2016). Standardization of fertigation schedule for tomato (Solanum lycopersicum L) under open precision farming. **Journal of Crop and Weed**. 12(2): 82-85.

Anan, P., & Mallika S. (2017). Supplementary Irrigation for Cassava Planted in the Late Rainy Season of Northeastern Thailand. **Asian Journal of Crop Science**. 9 (4): 100-108.

Atallah, T., Darwish, T., & El Moujabber, M. (2002). Modality of fertigation of protected cucumber and nitrogen use efficiency under field conditions. **Water Balance and Fertigation for Crop Improvement in West Asia**. 41-48.

Cuvaca, I. B., Eash, N., Zivanovic, S., Lambert, D. M., Walker, F. R., & Rustrick, B. (2015). Cassava (Manihot esculenta Crantz) tuber quality as measured by starch and cyanide (HCN) affected by nitrogen, phosphorus, and potassium fertilizer rates. **Journal of Agricultural Science**. 36-49.

Darwish, T., Atallah, T., Hajhasan, S., & Chranek, A. (2002). Comparative water and N fertilizer utilization in fertigation v/s soil application under drip and macro sprinkler systems of spring potatoes utilizing 15 N in Central Beqaa, Lebanon. **Water Balance and Fertigation for Crop Improvement in West Asia**. 49-60.

Darwish, T., Atallah, T., Khatib, N., & Karam, F. (2004). Fertigation and Conventional PotassiumApplication to Field Grown Potato in Lebanon: Perspective to Enhance Efficiency. In **IPI Regional Workshop on Potassium and Fertigation Development in West Asia and North Africa**.

EL Moujabber, M., Atallah, T., & Darwish, T. (2002). Crop modelling and water use efficiency of protected cucumber. **Water Balance and Fertigation for Crop Improvement in West Asia**. 61-67.

Ewais, M. A., Mahmoud, A. A., & Khalil, A. A. (2010). Effect of nitrogen fertigation in comparison with soil application on onion production in sandy soils. **Alexandria Journal of Agricultural Research**. 55(3): 75-83.

Gajek, F. (1971). Influence of mineral fertilizing during many years on the yields of cultivated plants as well as on some changes in soil properties. III. Yield components and chemical composition of plants. **Pamietnik Pulawski**. 50: 155-171

Ghiyal, V., & Bhatia, A. K. (2018). Effect of nitrogen levels and fertigation frequency on the growth parameters and yield of potato tuber (Solanum tuberosum L.) cv. Kufri Bahar. **Journal of Pharmacognosy and Phytochemistry**. 7(4): 2064-2067.

Howeler, R. H. (1985). Mineral nutrition and fertilization of cassava. In **Cassava: research, production and utilization. UNDP-CIAT Cassava Program**. (pp 249-320). Cali, Colombia.

Howeler, R. H. (2002). Cassava mineral nutrition and fertilization. **Cassava: Biology, Production and Utilization**, 115-147.

Howeler, R. (2006). Cassava in Asia: trends in cassava production, processing and marketing. In **Workshop on "Partnership in modern science to develop a strong cassava commercial sector in Africa and appropriate varieties by 2020**. 1-38.

มหาวิทยาลัยเทคโนโลยีสุรนารี

Imas, P., & John, K. S. (2013). Research Findings. Potassium Nutrition of Cassava. **International Potash Institute, 60 Anniversary**. 29:13-18.

Janat, M., & Somi, G. (2002). Comparative study of nitrogen fertilizer use efficiency of cotton grown under conventional and fertigation practices using 15 N methodology. **Water Balance and Fertigation for Crop Improvement in West Asia**. 85-98.

Jeelani, J., Shafiq, F., & Mushtaq, A. (2017). Effect of Varying Drip Irrigation Levels and Methods of NPK Fertilizer Application on Soil Water Dynamics, Water Use Efficiency and Productivity of Various Crops: A Review. **Int. J. Pure App. Biosci**. 5(3): 764-773.

Jenkins, P. D., & Ali, H. (2000). Phosphate supply and progeny tuber numbers in potato crops. **Annals of Applied Biology**. 136(1): 41-46.

Jeyakumar, P., Amutha, R., Balamohan, T. N., Auxcilia, J., & Nalina, L. (2008). Fertigation improves fruit yield and quality of papaya. In **II International Symposium on Papaya 851**. 369-376.

Johnston, A. M., & Bruulsema, T. W. (2014). 4R nutrient stewardship for improved nutrient use efficiency. **Procedia Engineering**. 83: 365-370.

Kachwaya, D. S., & Chandel, J. S. (2015). Effect of fertigation on growth, yield, fruit quality and leaf nutrients content of strawberry (Fragaria×ananassa) cv Chandler. **Indian J. Agric. Sci**. 85: 1319-1323.

Landis, T. D., Pinto, J. R., & Davis, A. S. (2009). Fertigation-Injecting Soluble Fertilizers into the Irrigation System. **Forest Nursery Notes**. 29(2): 4-13.

Liang, X., Gao, Y., Zhang, X., Tian, Y., Zhang, Z., & Gao, L. (2014). Effect of optimal daily fertigation on migration of water and salt in soil, root growth and fruit yield of cucumber (*Cucumis sativus* L.) in solar-greenhouse. **PloS One**. 9(1): e86975.

Malavolta, E., Graner, E. A., Coury, T., Sobr, M. B., & Pacheco, J. A. C. (1955). Studies on the Mineral Nutrition of Cassava (Manihot Utilissima Pohl.). **Plant Physiology**. 30(1): 81-82.

Mathias, L., & Kabambe, V. H. (2015). Potential to increase cassava yields through cattle manure and fertilizer application: Results from Bunda College, Central Malawi. **African Journal of Plant Science**. 9(5): 228-234.

Mazurczyk, W., Wierzbicka, A., & Trawczynski, C. (2009). Harvest index of potato crop grown under different nitrogen and water supply. **Acta Scientiarum Polonorum. Agricultura**. 8(4): 15-21.

Melgar, J. C., Schumann, A. W., & Syvertsen, J. P. (2010). Fertigation frequency affects growth and water and nitrogen use efficiencies of swingle citrumelo citrus rootstock seedlings. **HortScience**. 45(8): 1255-1259.

Mohammad, M. J., Al-Omari, M., Zuraiki, S., & Qawasmi, W. (2002). Nitrogen and water utilization by trickle fertigated garlic using the neutron gauge and ^{15}N technologies. **Water Balance and Fertigation for Crop Improvement in West Asia**. 15-25.

Mohan, M., Rathore, A. L., & Jha, S. K. (2018). Response of Drip Fertigation, Intra Row Seeding of Legume and Planting Geometry on Net Return of Summer Maize. **Int. J. Pure App. Biosci**. 6(2): 964-967.

Nair, P.G., Mohankumar, B., Prabhakar, M. and Kabeerathumma, S. (1988). Response of cassava to graded doses of phosphorus in acid lateritic soils of high and low P status. **Journal of Root Crops**. 14(2): 1-9.

Nair, P.G., and R.S. Aiyer. (1986). Effect of Potassium Nutrition on Cassava (2) Starch Characters. **Journal of Root Crops**. 12: 13-18.

Ngongi, A.G.N., Howeler, R.H. and MacDonald, H.A. (1977). Effect of potassium and sulphur on growth, yield, and composition of cassava. In **Proceedings 4th Symposium International Society of Tropical Root Crops**. IDRC, Ottawa, Canada. 107-113.

Olaiya, Abideen & Ao, Salami & Jg, Bodunde & Oi, Lawal & Hammed, Lateef. (2016). Field evaluation of yellow cassava varieties as affected by fertilizer types and rates in two agro ecologies of Nigeria. **International Research Journal of Agricultural Science and Soil Science**. 7(3): 46-50.

Omondi, J. O., Lazarovitch, N., Rachmilevitch, S., Boahen, S., Ntawuruhunga, P., Sokolowski, E., & Yermiyahu, U. (2018). Nutrient use efficiency and harvest index of cassava decline as fertigation solution concentration increases. **Journal of Plant Nutrition and Soil Science**. 181: 644-654.

Phiwngam, A., Anusontpornperm, S., Thanachit, S., & Wisawapipat, W. (2016). Effects of soil moisture conservation practice, irrigation and fertilization on Jatropha curcas. **Agriculture and Natural Resources**. 50(6): 454-459.

Phiwngam, A., Anusontpornperm, S., Thanachit, S., & Wisawapipat, W. (2016). Effects of soil moisture conservation practice, irrigation and fertilization on Jatropha curcas. **Agriculture and Natural Resources**. 50(6): 454-459.

Poramacom, N., Ungsuratana, A. O., Ungsuratana, P., & Supavititpattana, P. (2013). Cassava production, prices and related policy in Thailand. **American International Journal of Contemporary Research**. 3(5): 43-51.

Rajput, A., Rajput, S. S., & Jha, G. (2017). Physiological Parameters Leaf Area Index, Crop Growth Rate, Relative Growth Rate and Net Assimilation Rate of Different Varieties of Rice Grown Under Different Planting Geometries and Depths in SRI. **Int. J. Pure App. Biosci**. 5(1): 362-367.

Ramadass, S., & Ramanathan, S. P. (2017). Influence of Drip Fertigation Levels on Physiological Parameters of Aerobic Rice in Western Zone of Tamil Nadu, India. **Int. J. Curr. Microbiol. App. Sci**. 6(4): 2609-2613.

Román-Paoli, E., & Sotomayor-Ramírez, D. (2006). New fertigation recommendations for cassava in a non-traditional production system. In 42nd Annual Meeting, July 9-15, 2006, Carolina, Puerto Rico (No. 256273). **Caribbean Food Crops Society**. 437-442.

Sampathkumar, T., & Pandian, B. J. (2010). Effect of fertigation frequencies and levels on growth and yield of maize. **Madras Agric. J**. 97(7-9): 245-248.

Sangakkara, U. R., & Wijesinghe, D. B. (2014). Nitrogen fertilizer affects growth, yield, and N recovery in cassava (Manihot esculenta L. Crantz). **Communications in Soil Science and Plant Analysis**. 45(11): 1446-1452.

Santos, M. A. I., Fraguas, R. M., Braga, M. A., Marques, T. R., Duarte, M. H., dos Santos, C. M., ... & Correcirc, A. D. (2013). Antioxidants and chlorophyll in cassava leaves at three plant ages. **African Journal of Agricultural Research**. 8(28): 3724-3730.

Silber, A., Xu, G., Levkovitch, I., Soriano, S., Bilu, A., & Wallach, R. (2003). High fertigation frequency: the effects on uptake of nutrients, water and plant growth. **Plant and Soil**. 253(2): 467-477.

Silva, T. S., Braga, J. D., Silveira, L. M. D., & Sousa, R. P. D. (2013). Planting density and yield of cassava roots. **Revista Ciência Agronômica**, 44(2): 317-324.

Spear, S.N., Edwards, D.G. and Asher, C.J. (1978). Response of cassava, sunflower, and maize to potassium concentration in solution III. Interactions between potassium, calcium, and magnesium. **Field Crops Research**. 1: 375-389.

Streck, N. A., Pinheiro, D. G., Junior Zanon, A., Gabriel, L. F., Rocha, T. S. M., Souza, A. T. D., & Silva, M. R. D. (2014). Effect of plant spacing on growth, development and yield of cassava in subtropical environment. **Bragantia**. 73(4): 407-415.

Tahir, S., & Marschner, P. (2017). Clay Addition to Sandy Soil Reduces Nutrient Leaching-Effect of Clay Concentration and Ped Size. **Communications in Soil Science and Plant Analysis**. 48(15): 1813-1821.

Temegne, C. N., & Ngome, F. A. (2017). Fertility management for cassava production in the centre region of Cameroon. **Journal of Experimental Agriculture International**. 16(5): 1-8.

Thai Meteorological Department, 2016. Rainfall and Temperature of Nakhon Ratchasima Province. Source: https://www.tmd.go.th/en/province.php?id=20.

Westermann, D. T. (2005). Nutritional requirements of potatoes. **American Journal of Potato Research**. 82(4): 301-307.

CHAPTER V

GENERAL CONCLUSION AND RECOMMANDATION

In this study, two experiments were conducted to evaluate the effect of drip irrigation and fertigation on cassava production at the Suranaree University of Technology Farm, Nakhon Ratchasima, Thailand. Two recommended cassava varieties (Var. HB 80 and Var. RY) were planted as research crop in two textured soils (sandy clay loam soil and loamy sand soil). The first experiment included three treatments to investigate the water requirement and water application pattern of cassava under drip irrigation system and the effects of irrigation and fertigation on cassava production. The second experiment consisted of six treatments to explore different fertigation frequencies and fertilizer rates for cassava production in two different textured soils.

5.1 General conclusion

In this region, water was very scarce, and most source of water for planting crop came from rainfed. Drip irrigation played an important position in cassava production. The results of the first experiment confirmed that different water regimes through drip the irrigation based on the water balance equation affected the cassava tuber yield. The soil moisture content could be accurately predicted with the ETc and water balance model, which indicated that they can use for the drip irrigation cassava. Plant height, leaf nutrient contents (N P and K), tuber starch content, water use efficiency and fertilizer use efficiency of cassava were the highest through fertigation in both soils. It has revealed that the drip fertigation can be used for achieving higher tuber yield of cassava (80.1 ton/ha in SCL soil and 54.6 ton/ha in LS soil). The increasing rate of yield of drip irrigation treatments reached 70.3-87.2% in SCL soil, 60.5-84.5% in SL soil when compared with the rainfed treatment. The same total water requirement was 1025 mm in both soils. The total amount of supplied water was 373 mm for SCL soil and 403 mm for LS soil.

The increased yield of cassava depended on the adequate amount of fertilizers and appropriate frequency with fertigation. If the balance for a particular nutrient is positive, the nutrient will accumulate in the soil and be absorbed by the crop. In contrast, if the balance is negative depletion, and the soil's fertility status may deteriorate. Hence, it is important not only to apply the adequate amount of fertilizers but also the correct balance among the various nutrients. In the second experiment, it revealed that the fertigation with NB model obtained higher tuber yield, tuber starch content, water use efficiency and fertilizer use efficiency than other treatments. In general, Fertigation treatments were significantly better than soil fertilizer application treatment, NB model treatments were significantly better than DOA recommendation treatment, and High-frequency fertigation was significantly better than low-frequency fertigation. The low-frequency fertigation with NB model positively affected the growth parameters, fresh and dry weight LAI CGR and leaf nutrient contents (N P and K) at 120 DAP in SCL soil. After the 120 DAP, the high-frequency fertigation with NB model dominated the results of cassava production in SCL soil. However, the high-frequency fertigation promoted cassava growth from planting to harvesting in LS soil. The starch content, tuber number, harvest index and water use efficiency except the fertilizer use efficiency were the highest through the high-frequency fertigation with NB model in both soils. Fertilizer use efficiency responded negatively to the amount of applied fertilizers but positively to the fertigation frequency. The higher yield (90.1 and 70.2 ton/ha) and net income (144,780 and 91,435 B/ha) were produced through the high-frequency fertigation with NB model in SCL and LS soil, respectively. The overall results demonstrated that high-frequency fertigation with NB model improved the nutrient uptake and water use efficiency, thereby increasing the yield and starch content of cassava, and consequently enhanced the income of farmers.

5.2 Recommendation

Drip irrigation can remit the water shortage situation of crop growth in Northeast Thailand. This study recommends that the amount of water supply should be suitable for the cassava production, which depends on weather conditions, while the water application pattern would be based on soil textures. Different varieties of cassava planted in different textured soils can be suggested in drip irrigation and fertigation. As the results of fertigation frequency and rate, the higher yield and quality of cassava should be obtained through the high-frequency fertigation with NB model, which can be used as a recommendation for cassava farmers in this area.

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APPENDICES

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APPENDIX A

EXPERIMENT 1

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Figure A-1 Drip irrigation compared with rainfed in SCL soil at 120 DAP.

Figure A-2 Drip irrigation compared with rainfed in LS soil at 120 DAP.

Figure A-3 Var. HB 80 of cassava in SCL soil at 120 DAP.

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Figure A-4 Var. RY 72 of cassava in LS soil at 120 DAP.

APPENDIX B

EXPERIMENT 2

Figure B-1 Drip irrigation and fertigation system.

Figure B-2 Water pump and electrical equipment.

Figure B-3 Var. HB 80 of cassava in SCL soil at 60 DAP.

Figure B-4 Var. RY 72 of cassava in LS soil at 60 DAP.

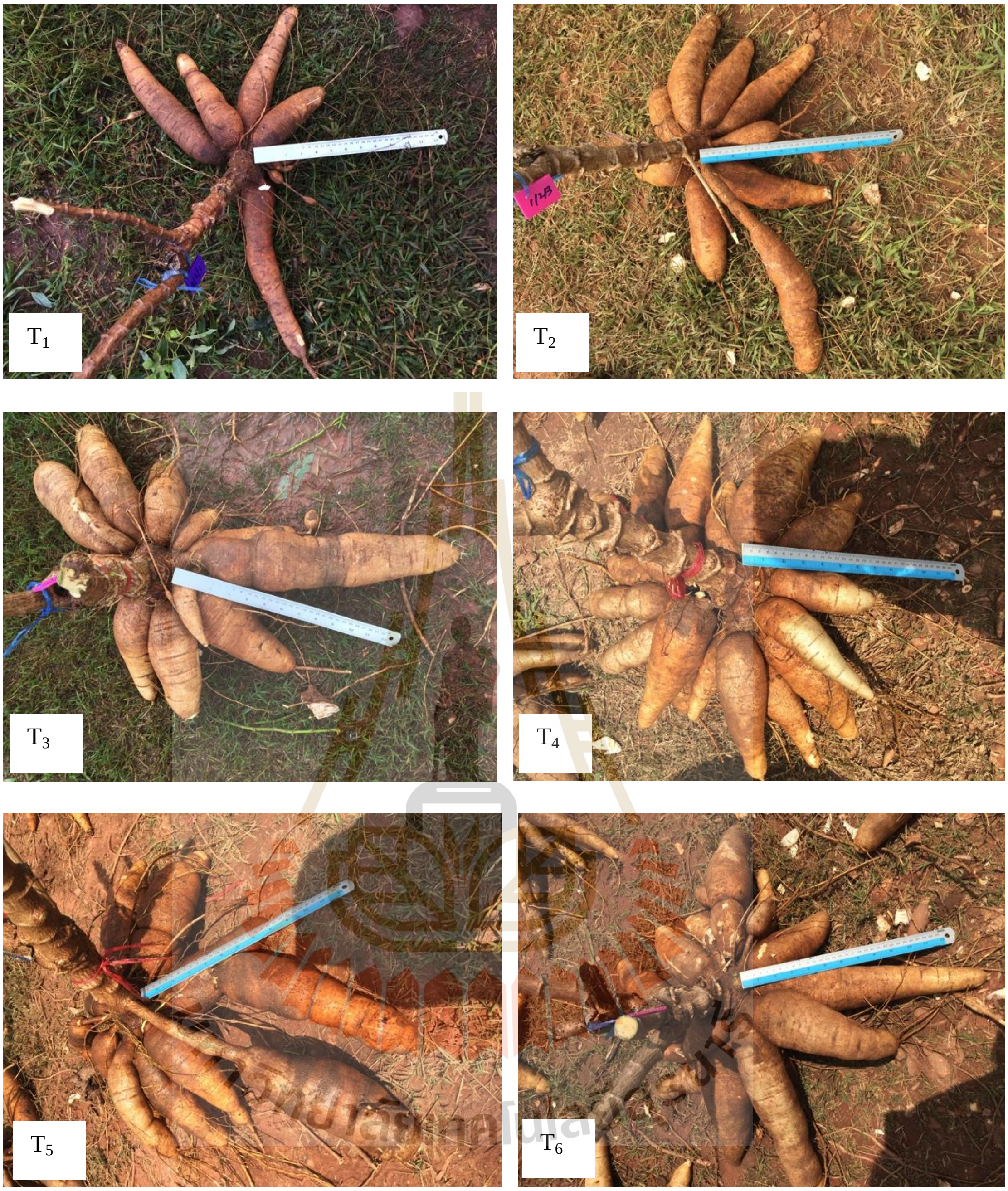

Figure B-5 Var. HB 80 of cassava tuber in SCL soil at harvesting.

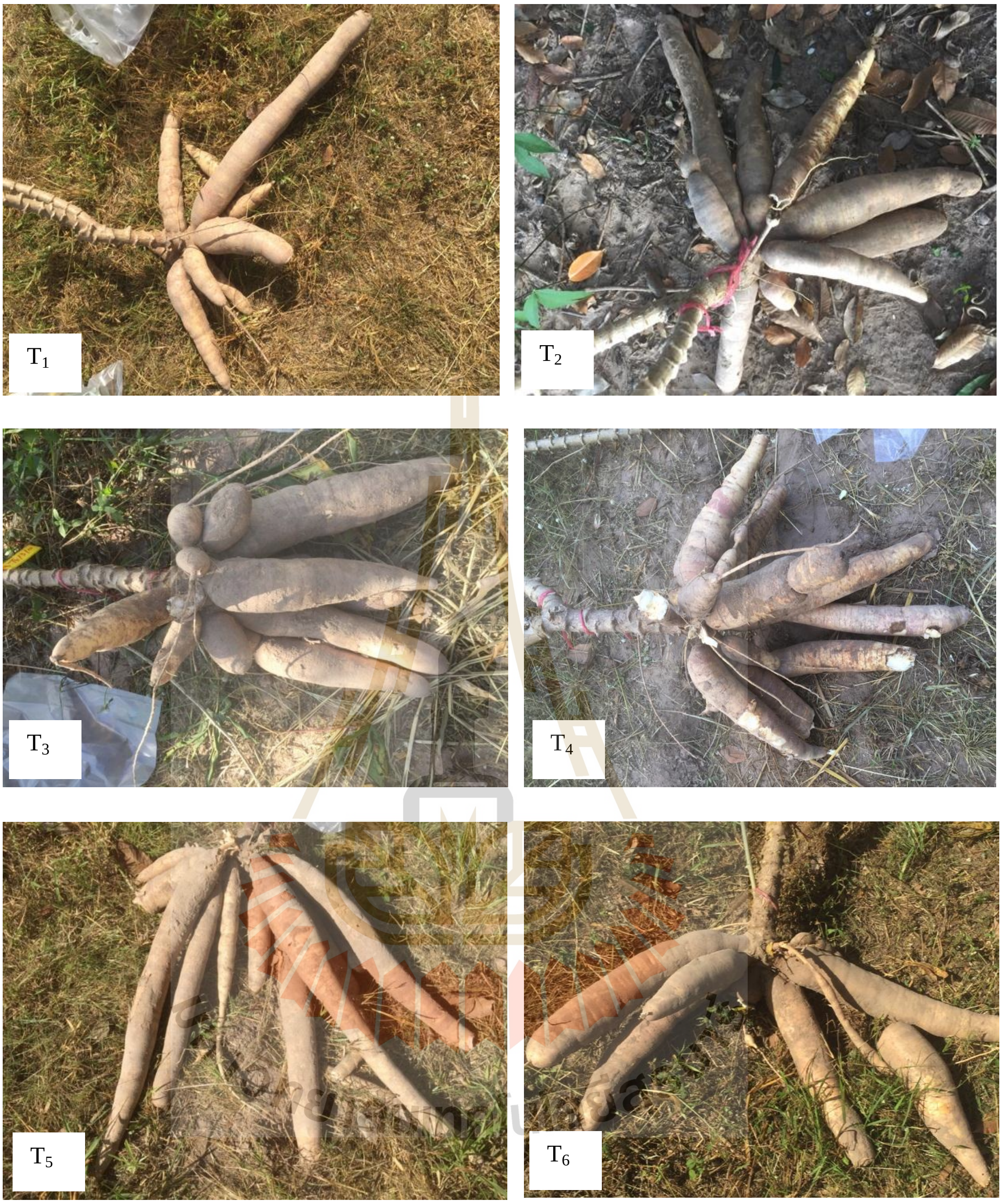

Figure B-6 Var. RY 72 of cassava tuber in LS soil at harvesting.

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Xie X., Ge H., Wang H., & Li Y. (2014). **Effect of different hydroponic formulations on growth of water spinach**. Environmental Protection and Technology, China.