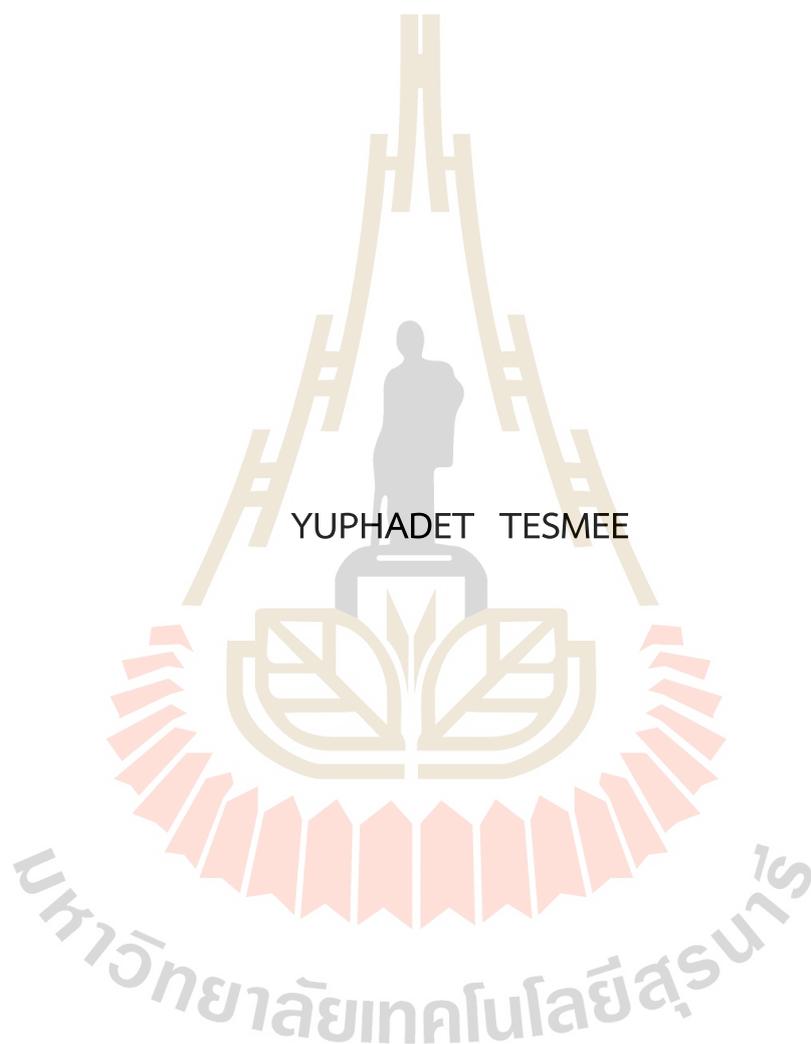


EFFECTS OF FERTIGATION ON YIELD AND RATOONING ABILITY OF  
SUGARCANE



A Thesis Submitted in Partial Fulfillment of the Requirements for the  
Degree of Master of Science in Crop Science  
Suranaree University of Technology  
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ผลของการให้น้ำและปุ๋ยในระบบชลประทานต่อผลผลิตและความสามารถในการไว้ตัวของอ้อย



วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต  
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มหาวิทยาลัยเทคโนโลยีสุรนารี  
ปีการศึกษา 2565

# EFFECTS OF FERTIGATION ON YIELD AND RATOONING ABILITY OF SUGARCANE

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for a Master's Degree.

Thesis Examining Committee

Arak Tira-umphon

(Asst. Prof. Dr. Arak Tira-umphon)  
Chairperson

Thitiporn Machikowa

(Asst. Prof. Dr. Thitiporn Machikowa)  
Member (Thesis Advisor)

S. Wornich

(Asst. Prof. Dr. Sodchol Wonprasaid)  
Member

P. Prasertsak

(Dr. Praphan Prasertsak)  
Member

Chatchai Jothityang

(Assoc. Prof. Dr. Chatchai Jothityangsoon)  
Vice Rector for Academic Affairs and  
Quality Assurance

N. Teumroong

(Prof. Dr. Neung Teumroong)  
Dean of Institute of Agricultural  
Technology

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คำสำคัญ: การจัดการน้ำ/การจัดการปุ๋ย/ระบบชลประทานแบบน้ำหยด/ศักยภาพในการไว้ตอ

อ้อยเป็นพืชที่สามารถให้ผลผลิตติดต่อกันได้หลายปีโดยไม่ต้องทำการปลูกใหม่ ทำให้สร้างผลตอบแทนให้กับเกษตรกรได้มาก เนื่องจากเกษตรกรไม่ต้องลงทุนในด้านของท่อนพันธุ์ และการเตรียมพื้นที่ใหม่ทุกปี แต่ในภาคตะวันออกเฉียงเหนือซึ่งเป็นพื้นที่ที่มีการปลูกอ้อยมากที่สุดของประเทศไทยนั้น เกษตรกรส่วนใหญ่สามารถไว้ตอได้ต่อเนื่องเพียง 1-2 ตอเท่านั้น เนื่องด้วยปัจจัยหลายอย่าง เช่น ความอุดมสมบูรณ์ของดินที่ต่ำ ปริมาณน้ำฝนน้อย และการจัดการที่ไม่เหมาะสม งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาวิธีการจัดการน้ำ และปุ๋ย เพื่อเพิ่มการเจริญเติบโต ผลผลิต และความสามารถในการไว้ตอของอ้อย โดยได้ทำการศึกษาต่อเนื่อง 2 ปี ในดิน 2 ชนิดคือ ดินร่วนเหนียวปนทราย (SCL) และดินทรายร่วน (LS) โดยการศึกษาในปีแรกทำในอ้อยปลูก มีการวางแผนการทดลองแบบ RCBD จำนวน 3 ซ้ำ กรรมวิธีการทดลองคือการจัดการอ้อย 3 วิธีการ ได้แก่ 1) การปลูกในสภาพน้ำฝน 2) การให้น้ำหยดและให้ปุ๋ยทางดิน และ 3) การให้น้ำหยดและปุ๋ยทางระบบน้ำ ซึ่งผลของการทดลองในปีที่ 1 พบว่า การปลูกอ้อยโดยการจัดการด้วยระบบน้ำหยดและให้ปุ๋ยทางระบบน้ำนั้นมีการเจริญเติบโต และผลผลิตสูงที่สุดในดินทั้ง 2 ชนิด โดยการจัดการด้วยการให้น้ำหยดและปุ๋ยทางระบบน้ำสามารถเพิ่มผลผลิตได้มากกว่าการจัดการในสภาพน้ำฝน 78.0 % และ 46.2 % ในดินร่วนเหนียวปนทรายและดินทรายร่วนตามลำดับ ในปีที่ 2 ได้ทำการศึกษาผลของการจัดการในปีที่ผ่านมาและการจัดการในปีปัจจุบันต่อการเจริญเติบโตและผลผลิตของอ้อยต่อที่ 1 โดยวางแผนการทดลองแบบ Spilt plot design จำนวน 3 ซ้ำ โดยที่ปัจจัยหลักคือ ผลของการจัดการที่ผ่านมาในอ้อยปลูกทั้ง 3 กรรมวิธีคือ 1) การปลูกในสภาพน้ำฝน 2) การให้น้ำหยดและปุ๋ยทางดิน และ 3) การให้น้ำหยดและปุ๋ยทางระบบน้ำ และปัจจัยรอง คือการจัดการในปีปัจจุบันในอ้อยต่อที่ 1 ซึ่งแบ่งเป็น 2 กรรมวิธี คือ 1) การปลูกโดยอาศัยน้ำฝน และ 2) การให้น้ำหยดและปุ๋ยทางระบบน้ำ ผลการทดลองบ่งชี้ว่าผลจากการดูแลและจัดการในอ้อยในปีที่ 1 (อ้อยปลูก) มีอิทธิพลน้อยมากต่อการเจริญเติบโตและผลผลิตในอ้อยต่อ แต่ผลของการจัดการในปีปัจจุบันเป็นตัวบ่งชี้การเจริญเติบโตและผลผลิตของอ้อยต่อ โดยการจัดการอ้อยต่อที่เหมาะสมสามารถปรับปรุงประสิทธิภาพการผลิตจากการดูแลที่ไม่เหมาะสมในปีที่ 1 ให้เพิ่มขึ้นเทียบเท่ากับการดูแลที่เหมาะสมในปีแรก โดยในด้านของผลผลิตพบว่าการให้น้ำหยดและปุ๋ยทางระบบน้ำนั้นสามารถเพิ่มผลผลิตของอ้อยต่อที่ 1 ได้สูงกว่าการจัดการปลูกในสภาพน้ำฝน เฉลี่ย 27.5% และ 31.9 % ในดินร่วนเหนียวปนทรายและในดินทรายร่วนตามลำดับ สำหรับการประเมินประสิทธิภาพในการไว้ตอของอ้อย (Ratooning ability) ซึ่งเป็นการเปรียบเทียบ

การเจริญเติบโต ผลผลิต และองค์ประกอบของอ้อยต่อกับอ้อยปลูก พบว่าผลจากการจัดการทั้งในอ้อยปลูกและในอ้อยต่อมีผลต่อความสามารถของการไว้ตอของอ้อย โดยในอ้อยปลูกซึ่งอาศัยสภาพน้ำฝนทำให้อ้อยสร้างและสะสมองค์ประกอบของชิ้นส่วนใต้ดินมากที่สุด (ราก และ เหง้า) ซึ่งองค์ประกอบของชิ้นส่วนใต้ดินเหล่านี้มีผลในเชิงบวกต่อการงอกและการเจริญเติบโตของอ้อยต่อในระยะแรก ทำให้อ้อยที่ปลูกในสภาพน้ำฝนในปีแรกมีความสามารถการไว้ตอสูง ส่วนอ้อยที่ปลูกในสภาพน้ำหยดมาก่อนแล้วกลับมาดูแลในสภาพน้ำฝนทำให้มีความสามารถในการไว้ตอลดลง ดังนั้นในการปลูกอ้อยภายใต้ระบบน้ำหยดจำเป็นต้องมีการใช้ระบบน้ำหยดอย่างต่อเนื่องเพื่อไม่ให้ประสิทธิภาพการไว้ตอลดลง สำหรับการปลูกในสภาพน้ำฝนในปีแรกนั้นสามารถเปลี่ยนมาใช้ระบบน้ำหยดในอ้อยต่อที่ 1 ได้โดยที่ศักยภาพการไว้ตอไม่ได้น้อยไปกว่าการปลูกในระบบน้ำหยดตั้งแต่ปีแรก



สาขาวิชาเทคโนโลยีการผลิตพืช

ปีการศึกษา 2565

ลายมือชื่อนักศึกษา สุเมธ ชาติดี

ลายมือชื่ออาจารย์ที่ปรึกษา ร. 2

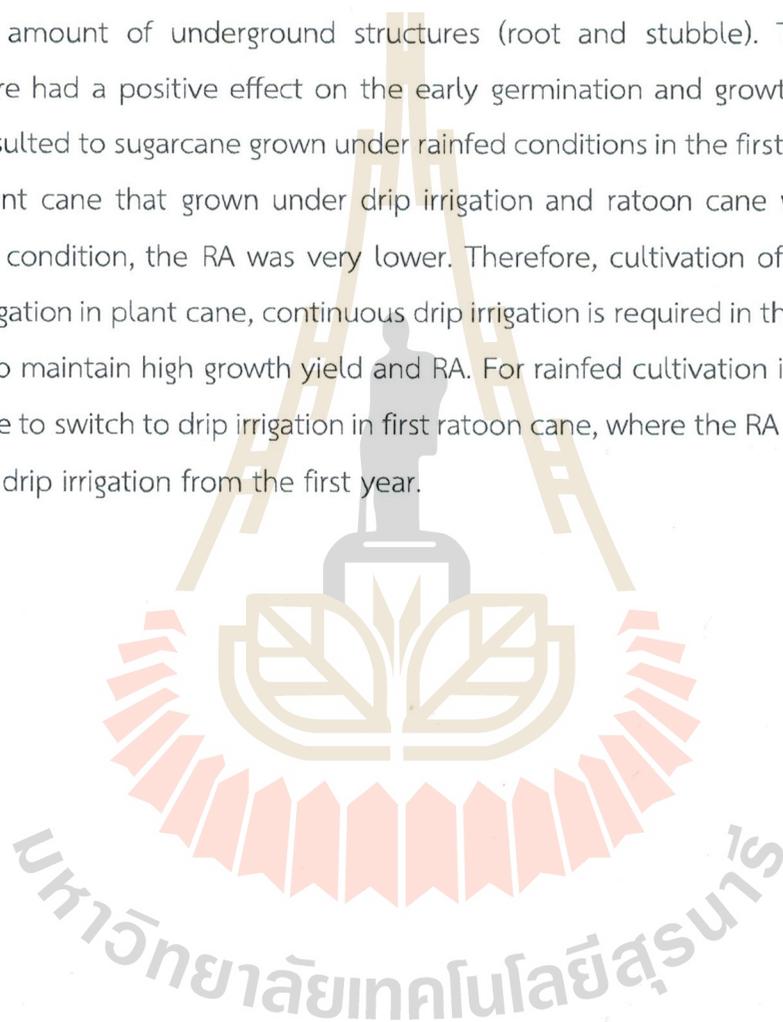
ลายมือชื่ออาจารย์ที่ปรึกษาร่วม ล. 8

YUPHADET TESMEE : EFFECTS OF FERTIGATION ON YIELD AND RATOONING ABILITY OF SUGARCANE. THESIS ADVISOR : ASST. PROF. THITIPORN MACHIKOWA, Ph.D., 77 PP.

Keywords: Water management/Fertilizer management/Fertigation/Ratooning potential

Sugarcane is a crop that can be reproduced for several years without replanting. Therefore, farmers can generate great income by reducing the cost of stock materials and land preparation. However, in the Northeastern of Thailand (the largest sugarcane production area) only 1–2 ratoons of sugarcane can be maintained by most farmers due to several factors such as low soil fertility, low rainfall, and unsuitable crop managements. The aims of this research were to study water and fertilizer management for growth and yield enhancement and to improve the ratooning ability of sugarcane. The series of two–year experiment was conducted in 2 soil textures i.e., sandy clay loam (SCL) and loamy sand (LS). In the first year, the experiment was conducted in plant cane (PC) to compare the effects of water and fertilizer management. The experimental design was randomized complete block design with 3 replications. Treatments were 3 water and fertilizer managements including i) Rainfed conditions (traditional management), ii) Drip irrigation with soil fertilizer application, and iii) Drip fertigation. The results showed that drip fertigation had the highest growth and yield performances in both soils. Drip fertigation produced 78.0% and 46.2% higher yield than rainfed conditions in SCL and LS soils, respectively. In the second year, the experiment was conducted in first ratoon cane (FRC) to study the effects of residual practices and current year practices on growth and yield of FRC. The experimental design was split plot design with 3 replications. The main plot was 3 residual practices of the previous crop including i) Rainfed conditions ii) Drip irrigation with soil fertilizer application and iii) Drip fertigation, and the subplot was 2 current year practices in FRC including i) Rainfed conditions and ii) Drip fertigation. The results showed that the residual effects of the previous crop had low influence on the growth and yield performance of FRC, but the current crop practices were the main factor that indicated growth and yield of next ratoon cane. The suitable practice in FRC could improve the production efficiency of FRC from the unsuitable management in first year to be the

same as suitable practice. In term of yield production, drip fertigation in FRC produced average higher yields of 27.5% and 31.9% than the rainfed conditions in SCL and LS soil respectively. For the assessment of ratooning ability (RA) which was a comparison of growth, yield and yield components of PC with ratoon cane, it was found that both managements (previous and current crop) affected the RA of sugarcane. For the previous crop (PC), sugarcane under rainfed conditions produced and accumulated the largest amount of underground structures (root and stubble). This underground structure had a positive effect on the early germination and growth of ratoon cane that resulted to sugarcane grown under rainfed conditions in the first year had high RA. For plant cane that grown under drip irrigation and ratoon cane was grown under rainfed condition, the RA was very lower. Therefore, cultivation of sugarcane under drip irrigation in plant cane, continuous drip irrigation is required in the ratoon canes in order to maintain high growth yield and RA. For rainfed cultivation in plant cane, it is possible to switch to drip irrigation in first ratoon cane, where the RA was not less than that of drip irrigation from the first year.



School of Crop Production Technology

Academic year 2022

Student's Signature Yupadet Tesmee

Advisor's Signature [Signature]

Co-Advisor's Signature S. Wannial

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Finally, I hope my research will be important information for those who are interested.

YUPHADET TESMEE

มหาวิทยาลัยเทคโนโลยีสุรนารี

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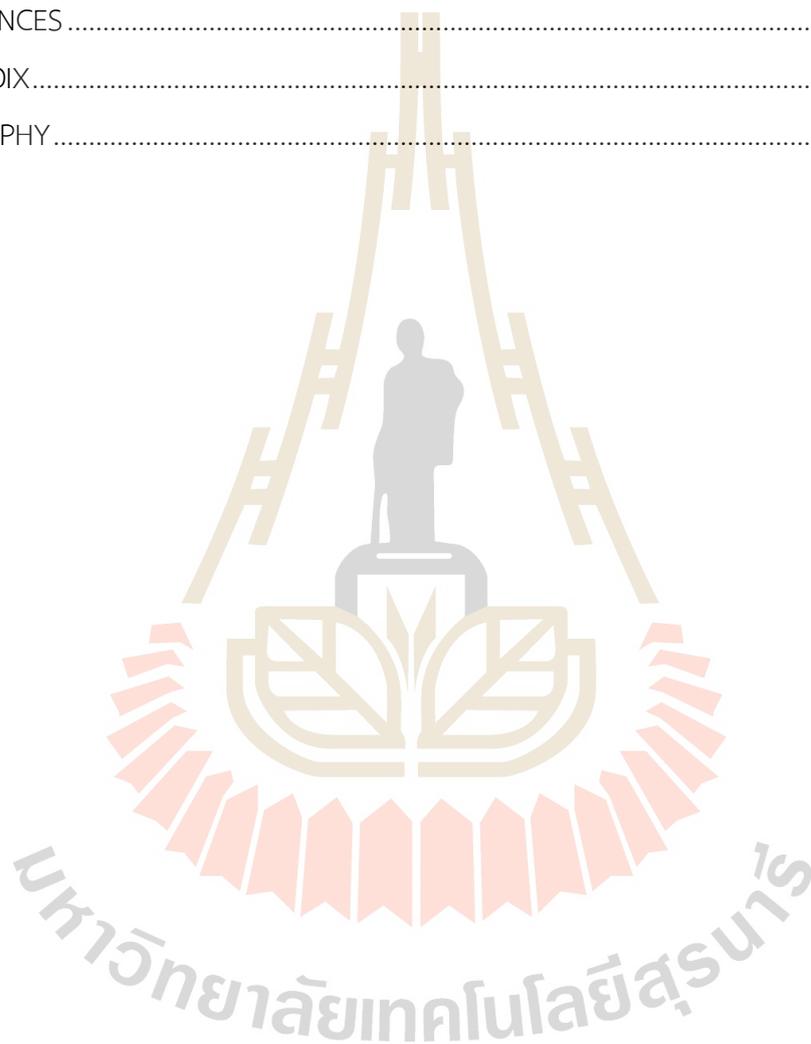
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## LIST OF ABBREVIATIONS

Av. P	=	Available P
AWHC	=	Available water holding capacity
DAH	=	Day after harvest
DR	=	Drainage
Dr	=	Root depth
EC	=	Electric conductivity
Epan	=	Class A Pan Evapotranspiration
ET	=	Evapotranspiration
Etc	=	Crop evapotranspiration
ETo	=	Amount of water consumed by standard or reference crop
Etp	=	Potential evapotranspiration
Ex. K	=	Exchangeable K
FC	=	Field capacity
FNUE	=	Fertilizer nutrient use efficiency
FRC	=	1 <sup>st</sup> ratoon cane
GA	=	Ground area
I	=	Irrigation
IWUE	=	Irrigation water use efficiency
Kc	=	Crop coefficient
Kp	=	Class A Pan coefficient
LA	=	Leaf area
LAI	=	Leaf area index
LS	=	Loamy sand soil
MAP	=	Month after planting
MAH	=	Month after harvesting
NB	=	Nutrient balance model
NMC	=	Number of millable cane

### LIST OF ABBREVIATIONS (Continued)

NS	=	Nutrient supply
NR	=	Nutrient required for the target yield
NUE	=	Nutrient use efficiency for soil uptake
OM	=	Organic matter
PC	=	Plant cane
P	=	Precipitation
PWP	=	Permanent wilting point
RA	=	Ratooning ability
Re	=	Effective rainfall
RL	=	Root length
RLD	=	Root length density
RO	=	Surface runoff
RWC	=	Relative water content
SAN	=	Soil available nutrient
SCL	=	Sandy clay loam soil
SDI	=	Surface drip irrigation
SM	=	Minimum amount of soil nutrient
SMC <sub>p</sub>	=	The predicted soil moisture content
SCMR	=	SPAD chlorophyll meter reading
SV	=	Soil volume
TVD	=	Top visible dewlap
WUE	=	Water use efficiency

# CHAPTER I

## INTRODUCTION

### 1.1 Background of this study

Sugarcane (*Saccharum officinarum* L.) is an important economic crop in the world, which is most often planted in tropical and sub-tropical zones due to it being the C4 plant and can acclimatize to high temperatures and humidity. Globally, more than 100 countries are producing sugarcane, but productivity widely different between the countries. The largest producers are Brazil (41%), India (16%), China (6%), and Thailand (6%), which together account for over 50% of global sugarcane production (Figuroa-Rodríguez et al., 2019). Sugarcane productivity is mostly used to produce sugar and is the raw material of many industrial sectors i.e., alcohol, food, feed, and seasoning.

Sugarcane is Thailand's fourth most important commercial field crop, inferior only to rice, cassava, and para rubber. Thailand's northeastern region is the biggest sugarcane producing area and in 2018/19. This region had about 5.3 million rai which was about 43.6% of Thailand's total sugarcane producing area. The region produces 58.7 million tons of fresh's products. The average production in the northeastern region is 10.9 tons/rai (Office of the Cane and Sugar Board, 2018), which is very low compared to its potential yield. Therefore, the improvement of sugarcane production in the northeastern region will affect Thailand's total sugarcane production.

Generally, most of the sugarcane produced in the northeast is from rainfed agriculture and planted towards the end of the rainy season, which can increase the risk of water deficit in the beginning stage (3–5 months after germination). Besides extended dry conditions can also result in poor fertilizer uptake efficiency, since there is insufficient water in the soil. One of the main abilities of the water to all plants is a dissolvent of the ion, which ensures that fertilizer is transported from the soil to any part of the plant. When sugarcane experiences long dry conditions and poor fertilizer uptake, it will reduce the amount of stalk and biomass accumulation (Jangpromma et al., 2012), consequently, it will reduce yield and quality. Furthermore, low biomass accumulation can also affect the next year ratoon crop (Shrivastava et al., 2016; Yadav, 1991).

most of sugarcane farmers normally like to have two or more sugarcane ratoons because the investment is lower than new plant crop by 25–30% along with saving stalk material (Singh et al., 2014).

However, most of the farmers could not produce more than two ratoon crops and the ratoon crop also has limited productivity. The inefficiency of management and unpredictable conditions from preceding crop including water stress, nutrient deficit, etc., can affect the ratooning ability and ratoon crop productivity.

Drip irrigation is an efficient irrigation method, which can provide water directly into the soil at the plant root zone, thus minimizing conventional loss due to deep percolation, runoff, or soil erosion. It also permits the utilization of water-soluble fertilizer along with irrigation water (fertigation) (Sathiyaraj and Priya, 2017). Fertigation can enhance fertilizer uptake and reduce the risk of fertilizer loss resulting in higher yields and better-quality products. It appears to be the best solution for many problems in dryland agriculture and enables economical use of the water supply, high crop uniformity, and high water and nutrient use efficiency in several crops. It would be the best way to solve the problem of low yield and ratooning ability in sugarcane under the northeastern's conditions if irrigation control and fertilizer application are optimized.

This research aimed to investigate the effect of fertigation under drip irrigation on sugarcane yield, dry matter accumulation, and ratooning ability in two different texture soils in the northeastern conditions.

## 1.2 Objectives of the study

- 1) To compare the effects of drip irrigation with rainfed conditions on growth, yield, and quality of sugarcane.
- 2) To compare the effects of fertigation and soil fertilizer application under drip irrigation on growth, yield, and quality of sugarcane.
- 3) To evaluate the impact of fertigation on dry matter and stool accumulation and ratooning ability of sugarcane.

## CHAPTER II

### LITERATURE REVIEWS

#### 2.1 Importance of sugarcane

Sugarcane is a plant of the Gramineae family, which is the same family as grass, bamboo, and grains. Sugarcane is the most planted in the world and the global productivity exceeds 180 million tons (United States Department of Agriculture, 2022). It is cultivated on more than 20 million hectares and in more than 100 countries. It is an important crop for many sugar-exporting countries, including Brazil, India, and Thailand. Typically, sugarcane is generally used to produce sugar and it is related to many products, such as electricity, bioethanol, and soil improvement materials, accounting for almost two-thirds of the world's production and has lately gained increased attention because of ethanol production. Sugarcane bagasse (the waste product generated by sugar mills after sucrose extraction from cane juice) is largely used for energy cultivation in mills or to produce animal feed, increasing the overall efficiency of the crop system. Recently, there has been increased interest in using bagasse for industrial processes such as paper production, dietary fiber in bread, as a wood substitute in the production of wood composite, and the synthesis of carbon fibers (Sangnark and Noomhorm, 2004)

#### 2.2 Growth of sugarcane

Sugarcane is a perennial crop that can be planted in 1<sup>st</sup> year (plant cane) and managed continuously for many years (ratoon cane). It has divided into 4 genera including *S. officinarum* L., *S. spontaneum* L., *S. barberi* Jews., and *S. robustum*. Generally, *S. officinarum* is the most planted genus in the world. The sugarcane growth stage is divided into 4 phases.

i) Germination phase, this phase starts from planting until shoots germinate in the soil, during this period, it will take approximately about 2–3 weeks, which depends on many factors such as varieties, soil types, and environmental conditions.

The number of seedlings will determine the sugarcane products per unit area.

ii) Tillering phase starts from 1.5 to 2.5–4 month after planting (MAP). Clumping is a physiological process of repetition under the ground. The factors that affect the tiller population include soil moisture, light, temperature, and fertilizer. When shoots germinate early, they will be strong, but if they germinate late, they will be a chance to die or not fully grow. Controlling water and weeds is essential during the tillering phase, which stimulates the number of shoots and consequently affects sugarcane yield.

iii) Stalk elongation phase, this phase occurs from 3–4 MAP until about 7–8 MAP. Sugarcane will increase the length and stalk diameter quickly, and after this phase, its growth will be slow and start the sugar accumulation.

iv) Maturity and ripening phase, this phase has a slower growth rate than the other phases. When growth slows down, the sugar produced from leaf photosynthesis is less and most of the sugar accumulates in the stalk. At the beginning of maturation, sugar accumulation will start from the base to the tip of the sugarcane. Therefore, the base is sweeter than the tip, and the sugar accumulation will increase accordingly until the whole stalk has a similar sweetness (ripen).

### **2.3 Significant of sugarcane in Thailand**

Sugarcane is a major contributor to global sugar production. It contributes about 60% of the total world sugar production (Onwueme and Sinha, 1999). It is one of the most important crops in Thailand. Thailand is fourth largest in world sugarcane production inferior to Brazil, India, and China. However, for sugar export, Thailand is the second largest in sugar exporting after Brazil. Nowadays, sugarcane can be grown in every part of Thailand, and it has related to many parts of industries including replaceable energy, ethanol, spirits, paper, and the food industry. In the production year of 2018/19, Thailand produced 180,000 million Bath from sugar and other related by products. Presently, Thailand has 50 sugar factories and will potentially increase to 62 factories in the future. It has shown the high efficiency of sugarcane and sugar production in Thailand (Office of Cane and Sugar Board, 2019).

## 2.4 Limitation of sugarcane production

Sugarcane could plant in every part of Thailand, but the biggest production area is in the northeast. Most of the sugarcane in this area is largely grown under rain-fed conditions in the arid and semi-arid tropical zone. Most sugarcane farmers normally like to have two or more sugarcane ratoons because of the heavy investment of input for new planting. However, most farmers could not produce more than two ratoon crops and the ratoon crops usually have limited productivity compared to the plant crop. The low yield of ratoon crops is mainly due to the low ratooning potential of cultivars and suboptimal crop management. In research of Chumphu et al. (2019) reported that poor ratooning ability of sugarcane caused limit crop productivity and profitability of growers. This is associated with the physiological processes and root distribution patterns on the yield of the second ratoon cane. Moreover, sugarcane genotypes were factor that significantly different for root length density (RLD), germination percentage, and yield of ratoon cane. High RLD between plants in the upper soil layers at 90 day after harvest (DAH) was positively correlated with high germination of ratoon crops, whereas high RLD between rows in the lower soil layers at 90 and 270 DAH was associated with high cane yield. Relative Water Content (RWC) at 90 DAH and stomatal conductance at 180 DAH were closely related to germination percentage, whereas chlorophyll fluorescence and stomatal conductance at 180 DAH were closely related to cane yield. It is assumed that the management and unpredictable conditions from preceding crops such as water stress and nutrient deficit that can affect physiological processes, growth, and dry matter accumulation in the new plant will affect the ratooning ability and ratoon crop productivity.

## 2.5 Importance of water to plants

Water is an important compound that is found on 3 in 4 of the world's surfaces. About 97% is saline water, 2% is polar ice and lower than 1% is fresh water (The American River Water Education Center, unpublished). In agriculture, water is very important for plant growth. It is an important element in various parts of plants and necessary for the physiological processes of plants. Typically, the amount of water contained inside plants is very small compared to the amount of water that is

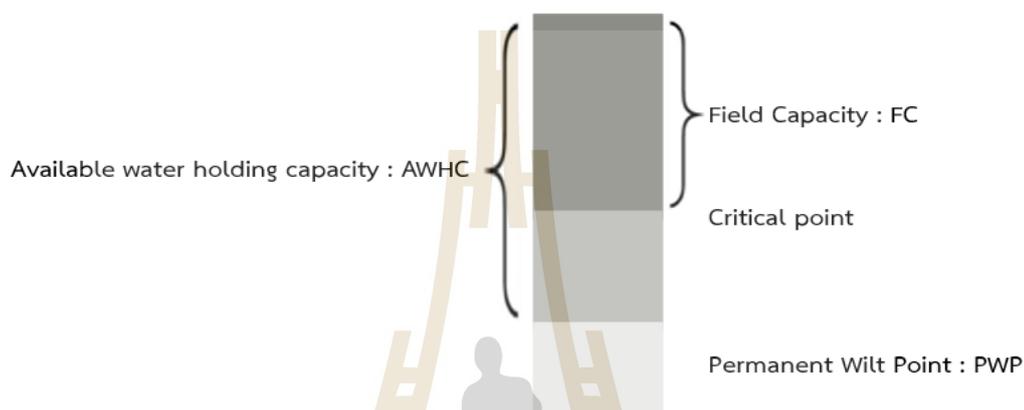
absorbed out of the soil through the plants and lost from transpiration. The conditions in which the water in the plant changes until it falls below an appropriate level directly affect the physiological processes, growth, yield, and quality of crop production. A study by Gentile et al. (2015) found that in drought stress conditions, sufficient soil water reduced below a critical point caused the yield-reducing by up to 60%. In addition, water also helps to dissolve mineral nutrients in the soil, so that the roots can absorb nutrients from the soil to the various parts of the plant, and it also helps the soil to be moist which makes the various processes normal in plants.

Sugarcane has been considered a high-water consumption crop. Therefore, water was the most important factor in the growth and productivity of sugarcane in the northeast. FAO (Unpublished) reported that sugarcane is highly sensitive crop for drought stress, and it needed average water of around 1,500–2,500 mm per crop cycle. Additionally, under rainfed conditions sugarcane would grow under water shortage conditions within 5–6 months in the northeast region of Thailand due to the amount of average rainfall being less than 10 mm/month from November to March. Because of the low precipitation and the uneven rainfall distribution, coupled with most of the soil being sandy soil that cannot store an abundant amount of moisture, it often encounters a water shortage that will lead to a decline in yield. Therefore, additional water is needed for sugarcane, but sometimes the consumption of irrigation water will be increased or wasted. For example, if the amount of irrigation water exceeds the water holding capacity, the excess water will be leaching or evaporating from the soil surface into the air. The amount of water loss is higher than the root absorption. In addition to the water loss, nutrients will also lose with the disappearing water. To solve the problem of the amount of irrigation water and improve water use efficiency, a reliable irrigation system should be used along with good irrigation management.

## **2.6 Irrigation and crop evapotranspiration (ETc)**

Soil moisture can be controlled by water supply in the plant roots zone between permanent wilting point (PWP) and field capacity (FC) or during the humidity range when the plants absorb water easily. Chadha et al. (2019) found that plant has the maximum growth increase when soil water was reduced from 30-65% of full AWHC,

and the sign stress showed when the soil moisture content was reduced to 75%. Soil moisture is allowed to reduction before the next water supply which is called allowable depletion. Soil moisture content between capillary water and absorbed water after plant absorption is called the critical point (Fig 2.1).



**Figure 2.1** The relationship between soil moisture and the determination of the water of plants.

Generally, the amount of water supply should be according to the water requirement of plants and AWHC of soil that can be measured by using a device of moisture measuring, which is a sensor that is used to measure the moisture of different soil layers accurately. Providing water to the plants before soil moisture decreases to the critical point that is required for soil moisture content to back to the FC. If the soil moisture content is lower than the critical point, it will affect the yield and quality of the plant. Providing water to plants using the reference crop evapotranspiration can ensure soil moisture content as possible as closing to FC.

The amount of irrigation water depends on crop water use (crop evapotranspiration) and irrigation efficiency. Determination of crop evapotranspiration using climate data is the easiest and most convenient way. Evapotranspiration is the function of soil evaporation and crop transpiration. Soil evaporation depends on the evaporated surface or uncover crop area and climate which is defined as the evaporative demand. The crop transpiration depends on the transpiration area (leaf) and also the climatological data. Therefore, if the climatological data can be monitored during a

specific crop growth stage, the crop water use, and irrigation amount can be predicted.

The climatological data can be used to predict the evaporation of water which is calculated by three equations.

i) Evapotranspiration (ETp) and Crop coefficient (Kc)

Crop coefficient (Kc) is defined as the ratio between Crop Evapotranspiration (ETc) and potential evapotranspiration (ETp), and the value range is 0–1 that can be changed, according to the type of plant, growth period, season, period of year and place. Kc has been collected for each plant in each growth stage, such as rice, sugarcane, vegetables, biennial crops, and field crops (Thongaram et al., 2002). The equation is shown as follows

$$Kc = \frac{ETc}{ETp}$$

The ETc can be calculated from the conversion equation.

$$ETc = Kc \times Etp$$

Reference Crop Evapotranspiration or potential evapotranspiration (ETp) is defined as the amount of water loss from the standard crop or reference crop (grass field or alfalfa) that covers the soil all year and obtains enough water at all times. The evaporation and transpiration can be affected by external factors, such as blowing the wind the to required ETp or depending on climate change solely. In addition to the direct measurements, ETp also can be calculated from the climate at the time and place of trial or place that will bring up to use. There was a gathered ETp in the provinces where it is distributed monthly from climate data average of 25 years (Thongaram et al., 2002).

ii) Crop coefficient (Kc), Class A Pan coefficient (Kp), and Class A Pan Evapotranspiration (Epan) where the value is read directly from equipment installed in the filed plot for the plant. The ETc equation is shown as follows

$$ETc = Kp \times Epan \times Kc$$

Where     $ET_c$     =    Crop Evapotranspiration  
               $K_p$      =    Class A Pan coefficient  
               $E_{pan}$     =    Class A Pan Evapotranspiration  
               $K_c$      =    Crop coefficient

iii) Class A Pan Evapotranspiration ( $E_{pan}$ ) and Class A Pan coefficient ( $K'_p$ ) The  $ET_c$  equation is shown as follows

$$ET_c = K'_p \times E_{pan} \times K_c$$

Where     $ET_c$     =    Crop Evapotranspiration  
               $K'_p$      =    Class A Pan coefficient  
               $E_{pan}$     =    Class A Pan Evapotranspiration  
               $K_c$      =    Crop coefficient

$ET_c$  calculated from climate data using  $ET_p$  and  $K_c$  is the most popular method because it can obtain results easily without installing equipment or measuring  $E_{pan}$ , but it needs  $ET_p$  of planting area and  $K_c$  value of crop from the report of Royal Irrigation Department (unpublished), which is listed in Table 2.1 and Table 2.2, respectively.

**Table 2.1** The crop coefficient ( $K_c$ ) value of sugarcane.

Months	Crop coefficient ( $K_c$ )						
	Modified Penman	Blaney-Criddle	Pan Method	Thornthwaite	Hargreaves	Radiation	Penman-Monteith
1	0.47	0.56	0.56	0.56	0.60	0.53	0.65
2	0.68	0.83	0.84	0.71	0.83	0.8	0.86
3	0.85	1.04	0.94	0.88	1.00	1.04	1.13
4	1.03	1.28	1.27	1.06	1.16	1.21	1.35
5	1.20	1.54	1.73	1.18	1.35	1.41	1.56
6	1.00	1.17	1.50	1.14	1.19	1.06	1.29
7	0.86	0.98	1.23	0.80	1.16	0.96	1.20
8	0.65	0.68	0.74	0.93	0.88	0.63	0.93
9	0.50	0.57	0.48	0.53	0.55	0.53	0.63
10	0.42	0.53	0.45	0.44	0.48	0.48	0.52

**Table 2.2** Potential evapotranspiration (ET<sub>p</sub>) of Penman–Monteith monthly in northeast Thailand.

Province	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Nong Khai	3.10	3.80	4.60	4.60	4.00	3.60	3.50	3.40	3.50	3.60	3.30	3.00
Loei	3.30	4.10	4.80	5.10	4.40	4.10	3.70	3.60	3.60	3.60	3.20	3.00
Udon Thani	3.30	4.10	4.90	5.20	4.60	4.10	3.70	3.60	3.60	3.70	3.70	3.20
Sakon Nakhon	3.40	4.10	4.90	5.00	4.40	4.00	3.60	3.40	3.90	3.90	3.60	3.30
Nakhon Phanom	3.30	3.90	4.30	4.50	4.00	3.50	3.40	3.30	3.50	3.60	3.60	3.20
Khon Kaen	3.70	4.20	5.10	5.00	4.70	4.30	3.90	3.70	3.60	3.80	3.80	3.60
Mukdahan	3.70	4.20	5.00	5.20	4.10	3.60	3.60	3.40	3.60	3.80	4.00	3.50
Mahasarakham	3.60	4.20	4.70	5.20	4.60	4.20	3.80	3.60	3.60	3.80	3.80	3.60
Kalasin	4.20	4.90	5.40	5.50	4.80	4.30	4.20	3.70	3.70	4.10	4.30	4.10
Chaiyaphum	3.60	4.20	5.00	5.10	4.50	4.10	3.80	3.60	3.60	3.80	3.90	3.50
Roi Et	3.50	4.10	4.70	4.80	4.20	3.90	3.80	3.60	3.60	3.60	3.70	3.50
Ubon Ratchathani	3.60	3.70	4.20	4.10	3.70	3.60	3.60	2.90	3.20	3.30	3.60	3.40
Srisaket	3.40	3.90	4.60	4.80	4.40	4.40	4.20	3.70	3.90	3.60	3.80	3.50
Nakhon Ratchasima	3.40	4.00	4.40	4.60	4.20	4.00	3.90	3.80	3.40	3.40	3.50	3.40
Surin	3.50	4.00	4.40	4.60	4.00	4.00	3.50	3.50	3.60	3.60	3.70	3.40
Buriram	4.20	4.80	5.30	5.50	4.70	4.70	4.10	3.70	3.60	3.90	4.10	4.00

## 2.7 Drip Irrigation system

At present, there are various irrigation systems for crop production e.g., flood irrigation, furrow irrigation, sprinkler, and drip irrigation. A suitable system for a specific area depends on many factors for example type of crops, soil type, slope, cost, labor, equipment, and water supply. Eswaran (2017) concluded that a suitable irrigation system for dry areas or water-limited areas is drip irrigation because of its benefit such as water saving, uniform application, easy management, low labor cost, decreased weed growth, increased crop yield, and improved quality of crop product. Niaz et al. (2009) compared furrow and drip irrigation on 3 vegetable crops (tomato, cucumber, and bell pepper) and reported that drip irrigation used less of water amount for crops production, produced higher yield, and increased water use efficiency of all crops compared to furrow irrigation, and the result is showed in Table 2.3.

**Table 2.3** Water use efficiency in tomato, cucumber, and bell pepper through furrow and drip irrigation.

Crop	Amount of water (m <sup>3</sup> )		Yield (kg/acre)		WUE (kg/m <sup>3</sup> )	
	Furrow	Drip	Furrow	Drip	Furrow	Drip
Tomato	12,949	4,072	9,377	9,641	0.72	2.37
Cucumber	5,783	1,804	2,199	3,407	0.38	1.89
Bell pepper	13,403	4,319	5,194	5,251	0.39	1.22

## 2.8 Fertigation

Fertigation is an efficient technique for fertilizer and water management. It is a compound word that comes from fertilizer and irrigation. Soluble fertilizers can be injected directly into the irrigation system. 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. Characteristics of solid fertilizers for fertigation should include high quality, high solubility and purity, low salt level, and acceptable pH (Kafkafi and Tarchitzky, 2011). Fertilizer solubility is very important in fertigation. Fertigation tape will be clogged if fertilizers cannot be dissolved in the irrigation water.

The compatibility of fertilizers is another important characteristic of fertilizers. Sometimes fertilizers are likely to precipitate when two or more fertilizers are mixed. The pH of fertilizers has a relationship with precipitation in fertigation solutions. 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 the crop and increase the availability of some toxic element.

Fertigation was invented to tackle the problem of water shortage in the desert area and spread rapidly all over the world. Water is injected into fertigation lines by injection pump. The fertigation lines can give water a suitable flow environment and also prevent water evaporation. Fertigation can modify the humidity of the 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; Sand: 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 16.0% and 75.0%, respectively. Fertigation also can irrigate uneven areas such as hilly areas. It uses the optimum amount of water to produce the highest yield in agriculture. Higashide et al. (2007) used a fertigation system to produce tomatoes in the 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.

## 2.9 Fertigation in sugarcane

Sugarcane production in Thailand has mostly been planted under rainfed conditions. Therefore, most farmers have applied fertilizer with soil application 2 times at planting and between 3–4 month after planting (MAP). Under unpredictable rainfall, fertilizers are always non-available to plants and can be lost in intense conditions leading to low fertilizer use efficiency (Table 2.4). Fertigation can give the crop certain amounts of available nutrients during the growth cycle and ensures the correct doses of nutrients in different growth stages. There are several advantages such as accurate and uniform fertilization, the appropriate concentration of nutrients, effective uptake of nutrients, and lower nutrient loss and production costs. The efficiency between soil application and fertigation is shown in Table 2.5, F NUE of fertigation had higher by 80 to 90 percent than soil application which had a lower F NUE of 20–50 %. Kombali et al. (2016) found that subsurface drip fertigation can improve higher cane yield and yield parameters such as millable canes, cane length, internodes cane, cane girth, and single cane weight compared to furrow irrigation.

**Table 2.4** Explanation of loss pathways for nutrients.

Risk	Explanation
Leach	Nutrients loss by move below the rootzone of crops since the water draining through the soil profile.
Run	Nutrients loss from the application point caused of the water movement which is the soluble form or attached to sediments.
Blow	Nutrients lost by soil erosion or gaseous losses into the atmosphere.
Mine	The decline of soil fertility without nutrients removed, but the effective form turned into an insoluble mineral.

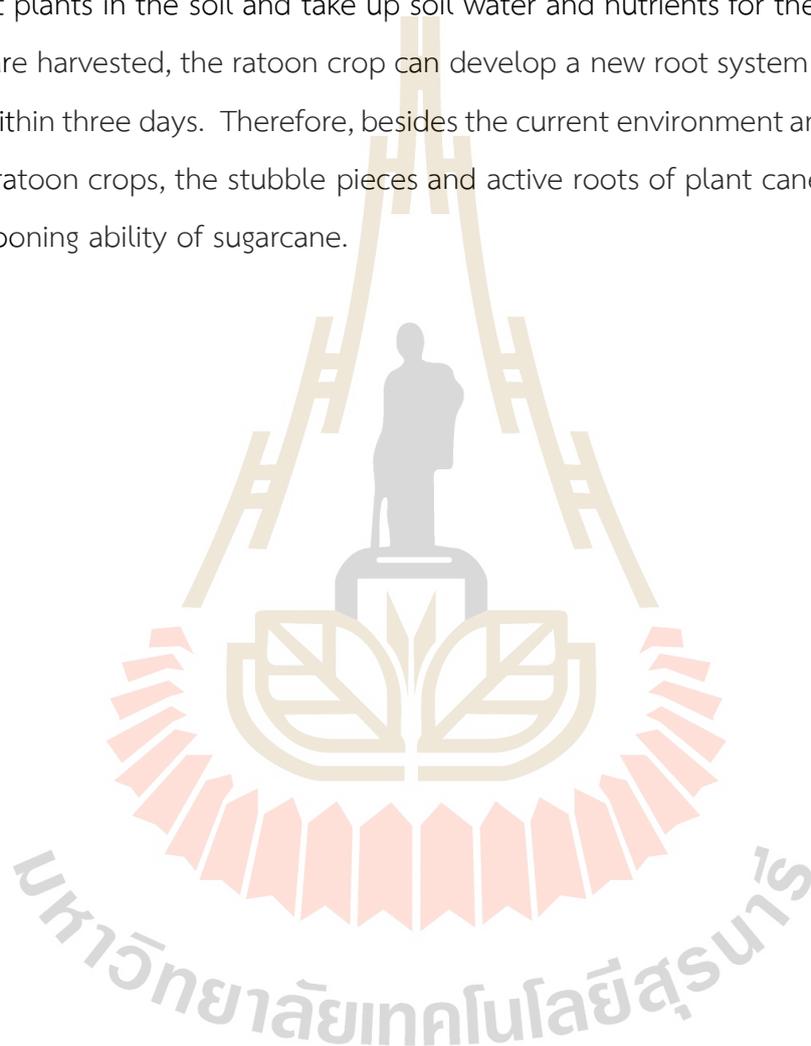
**Table 2.5** Fertilizer efficiencies of various application methods.

Nutrient	Fertilizer nutrient use efficiency (%)	
	Soil application	Fertigation
Nitrogen	30–50	95
Phosphorous	20	45
Potassium	50	80

## 2.10 Ratooning ability of sugarcane

The economics of sugarcane growing improve with the number of ratoon crops and their ratooning ability. Ratooning ability (RA) can be defined as the relative growth and yield performance of ratoon crops compared to plant crops such as the number of stalks, height, yield, and yield components. RA is responded to many factors including plant, environment, and management. The main plant characteristics which influence the ability to ratoon are the capacity to produce tillers, and tiller and stool survival. Modifying the influence of plant factors are climatic and soil factors such as moisture and soil aeration, which in turn may be modified by cultural operations such as the timing of harvest, nutrition, and traffic. Because ratooning is a complex process, there is a need to consider the various factors likely to influence the process. Ferraris and Chapman (1991) reported that the decline in cane yield with subsequent ratoons

was associated mostly with a decrease in stem weight rather than in stem number. Varieties with a higher yield of ratoon cane showed rapid canopy development and the rate of bud emergence from stubble pieces was enhanced by wetter rather than drier soil conditions. Trash conservation reduced bud development (Berding and Hurney, 2005) and ratooning ability of sugarcane. Roots function as an anchor to support plants in the soil and take up soil water and nutrients for the crop. After the canes are harvested, the ratoon crop can develop a new root system from old active roots within three days. Therefore, besides the current environment and management of the ratoon crops, the stubble pieces and active roots of plant cane might influence the ratooning ability of sugarcane.



## CHAPTER III

### MATERIALS AND METHODS

#### 3.1 Experimental site description

The experiments were conducted under typical field conditions with 2 different soil textures.

The first location was at Suranaree University of Technology, Nakhon Ratchasima, Thailand during the 2018/19 and 2019/20 planting seasons. The soil texture was sandy clay loam (SCL). The experimental field was 230 meters above sea level at 14°52'37" N latitude and 102°0'21" E longitude.

The second location was at KI sugarcane field, Buachet, Surin, Thailand with the same planting seasons as the first location. The soil texture was loamy sand (LS). The experimental field was 200 meters above sea level at 14°30'44.4" N latitude and 103°54'23.2" E longitude.

##### 3.1.1 Soil properties analysis

In both experiments, the soil samples were prepared for physical and chemical analysis before starting a new crop (Table 3.1). The sample was mixed well and used the quartering and coning method (Campos-M and Campos-C, 2017). Soil texture was determined by using a specific gravity technic by the hydrometer method (Bouyoucos, 1962). Bulk density was determined by the could method (Blake and Hartge, 1986). The soil AWHC was calculated from the field capacity (FC) and permanent wilting point (PWP) of the soil, which was determined by the pressure plate technic. Soil EC was determined with a 1:5 soil to water ratio by a conductivity meter. The pH was determined with a 1:1 soil-to-water ratio by pH meter. The organic matter was determined by the Walkley-Black acid digestion method (Walkley, 1947). The available P was determined by the Bray II method (Bray and Kurtz, 1945). Ammonium acetate and atomic absorption spectrophotometer were used to determine exchangeable K, Ca, and Mg (David, 1960).

**Table 3.1** Physical and chemical properties of soil.

Soil properties	SCL soil	LS soil
<b>Physical properties</b>		
Sand (%)	46.2	77.2
Silt (%)	22.5	23.1
Clay (%)	32.3	9.7
Bulk density (g/cm <sup>3</sup> )	1.25	1.35
AWHC (mm/cm)	1.65	1.12
<b>Chemical properties</b>		
<b>(2018/19)</b>		
pH	6.68	5.34
EC (dS/m)	0.031	0.233
OM (%)	1.43	0.63
Av. P (ppm)	12.7	5.8
Ex. K (ppm)	63.0	35.5
Ca (ppm)	2,030	442
Mg (ppm)	196	92
<b>Chemical properties</b>		
<b>(2019/20)</b>		
pH	6.77	5.27
Ec (dS/m)	0.072	0.049
OM (%)	1.08	0.62
Av. P (ppm)	2.93	4.95
Ex. K (ppm)	74.2	31.9
Ca (ppm)	2,150	459
Mg (ppm)	212	101

AWHC: Available water holding capacity; EC: Electric conductivity; OM: Organic matter; Av. P:

Available P; Ex. K: Exchangeable K; SCL: Sandy clay loam; LS: Loamy sand

### 3.2 Experimental design

The experiments were conducted in 2 planting seasons with different experimental designs. Khonkaen 3 variety was used in both locations, since it is the most important cultivar that planted 60-70% in Thailand cultivation. It produces good yield with long ratooning period and better sustain for disease (Tippayawat et al., 2012). Sugarcane was planted by double row practice, with the within-row spacing of 0.3 m and row spacing of 1.6 m.

The first-year experiment was conducted with the plant cane crop (PC) and treatments were arranged by Randomized Complete Block Design with 3 replications. Treatments were crop managements :

- T1: Rainfed conditions
- T2: Drip irrigation with soil fertilizer application
- T3: Drip fertigation

The second-year experiment was conducted with the first ratoon crop (FRC). The residual management of PC was splitted into 2 managements of FRC. The experimental design was Split Plot Design with 3 replications. Treatments were:

- Main plot:** the residue crop managements from PC
  - M1: Rainfed conditions
  - M2: Drip irrigation with soil fertilizer application
  - M3: Drip fertigation
- Subplot:** the crop managements in FRC
  - S1: Rainfed conditions
  - S2: Drip fertigation

### 3.3 Fertilizer application

In both soil textures and 2 continually year practices, the fertilizer was applied based on the nutrient balance model (NB). The major fertilizer sources were Urea (46-0-0), Monoammonium phosphate (12-61-0), Diammonium phosphate (18-46-0), and Potassium chloride (0-0-60). In soil application, the fertilizers were applied twice in the 1<sup>st</sup> and 3<sup>rd</sup> months. In fertigation, the fertilizers were fertigated equally every 3 weeks with 6 times from 1<sup>st</sup> to 5<sup>th</sup> months. The fertilizers were mixed and diluted with the water at the fertilizer: water ratio of 1:10 and injected into the drip irrigation system by a venturi pump.

The fertilizer rates of the nutrient balance model were calculated based on the nutrient balance equation (1) as the same study of Wonprasaid et al. (2021)

$$NS = \frac{NR-(SAN-SM)}{NUE} \quad (1)$$

Where NS is the nutrient supply (kg/rai), NR is the nutrient required for the target yield of 30 tons/rai, SAN is the amount of soil available nutrient that obtain from soil analysis (kg/rai) (Table 3.2), SM is the minimum amount of soil nutrient (OM=1%, P=10 ppm and K=60 ppm for SCL soil; OM=0.5%, P=5 ppm and K=30 ppm for LS soil) and NUE is nutrient use efficiency for soil uptake (N=80% P=60% and K=80%) for both soils.

**Table 3.2** Rate of fertilizers recommended based on water balance model in each soil textures.

Soil texture	Planting season	N (kg/rai)	P <sub>2</sub> O <sub>5</sub> (kg/rai)	K <sub>2</sub> O (kg/rai)
SCL	2018/19	16.0	12.0	25.0
	2019/20	16.0	12.0	25.0
LS	2018/19	22.0	16.0	35.0
	2019/20	22.0	16.0	35.0

### 3.4 Irrigation practice

In both year practices, the treatment of the rainfed condition was no water supplied and the drip irrigation treatments used the drip tape with the 2 l/hr./dropper and the dropper spacing of 30 cm. Water was irrigated based on the water balance model equation (2) (Pereira et al., 2020)

$$I=ET+DR+RO+\Delta W-P \quad (2)$$

where I is the irrigation, ET is the evapotranspiration, DR is drainage, RO is the surface runoff,  $\Delta W$  is the available water holding capacity (AWHC) and P is the precipitation.

The water was re-irrigated when the water content was reduced from FC (100 % AWHC) to a critical point (40 % AWHC). At 1–2 months of sugarcane age, the root

depths of 10 cm and 20 cm were used to calculate the water requirement of sugarcane, respectively. After 2 months until the harvest was calculated at 30 cm root depth

Daily water consumption was calculated by the same method as Xie (2018) based on equation (3).

$$ET_c = ET_o \times K_c \quad (3)$$

where  $ET_c$  is the crop evapotranspiration (mm/day),  $ET_o$  is the amount of water consumed by standard or reference crop (mm), and an average  $ET_o$  for 10 years (2010–2020) was used in this experiment.  $K_c$  is the crop coefficient.

The water content in soil was predicted by the same method as Xie which is shown in equation (4)

$$SMC_p = SMC_{p-1} - \frac{ET_c - R_e}{D_r} \times 100 \quad (4)$$

Where  $SMC_p$  is the predicted soil moisture content (%),  $n$  is the day of prediction,  $ET_c$  is the amount of crop requirement (mm/day),  $R_e$  is the amount of effective rainfall (mm), and  $D_r$  is the root depth (mm)

### 3.5 Sampling and data measurement

The recommended sampling area for double-row practice for data collection was 4.8 m x 4 m (19.2 m<sup>2</sup>) (Hassan et al., 2017)

#### 3.5.1 Plant cane (2018/19 growing season)

1) The plant height was measured from the soil base to the plant top visible dewlap (TVD) at 2, 4, 6, and 12 MAP.

2) The number of shoots was counted in the recommended area as mentioned earlier at 2, 4, 6, and in 12 MAP (number of millable cane, NMC)

3) Leaf area was measured at 4 MAP by Leaf Area Meter and leaf area index (LAI) was calculated by the Trimble method (2022) as in equation (6)

$$LAI = \frac{LA}{GA} \quad (6)$$

Where LAI is the leaf area index, LA is the leaf area(m<sup>2</sup>) and GA is the ground area(m<sup>2</sup>)

4) The leaf SPAD chlorophyll meter reading (SCMR) (SPAD unit) was measured at the 4 MAP by using a handheld portable chlorophyll meter (Minolta SPAD-502 Meter, Japan). The second fully expanded leaf from the Top Visible Dewlap (TVD) of each plant was used for these measurements, as previously described (Jangpromma et al., 2010). In brief, the data points were recorded at 6 positions along the length of the leaf blade and then the data points were averaged into a single value. Sugarcane was taken to ensure that the SPAD meter sensor fully covered the leaf lamina and that interference from the veins and midribs was avoided.

5) The Leaf nutrient including N, P, K, Ca, and Mg were analyzed in a young fully expanded leaf (4<sup>th</sup> leaf next from TVD) and samples were randomly collected from 10 plants at 6 MAP.

6) The stalk diameter (middle of the trunk) was measured by using a Vernier caliper from 10 canes in the recommended area at the 12 MAP.

7) Yield (tons/rai) was calculated from the harvest area of 4.8 m × 4 m (19.6 m<sup>2</sup>) at the 12 MAP.

8) Total soluble solid (TSS) (°Brix) was analyzed using a reflectometer.

9) Irrigation water use efficiency and fertilizer nutrient use efficiency were calculated during the harvest period.

10) Underground stubble fresh and dry weight in sub-soil after harvest was recorded in the 1 m<sup>2</sup> per replication at 12 MAP and was collected only in SCL soil.

11) Total RLD and RLD patterns of the PC were measured at 12 MAP only in the SCL soil. The auger method was used to collect the root samples. The auger consists of a coring tube with a diameter of 0.8 cm and a length of 80 cm which is designed to reduce compaction in the inner tube by improving the cutting edge and reducing the tube's thickness. Root samples were collected at the row center (0 cm), 20, 40, 60, and 80 cm apart from the planting line. They were taken at a depth of 80 cm and separated into 3 layers consisting of upper soil layers (0–20 cm), middle layers (21–40cm), and deeper layers (41–80 cm). Root samples of each layer were washed manually with water to

remove soil from the roots. Then they were analyzed to determine root length by program WinRHIZO 2013 basic, Reg, Pro & Arabidopsis for root measurement, Regent instrument Canada Inc. Root length density (RLD) was calculated as the same method of Faye et al. (2019) as in equation (7).

$$RLD = \frac{RL}{SV} \quad (7)$$

Where RLD is the root length density (cm/cm<sup>3</sup>), RL is the root length (cm) and SV is the soil volume (cm<sup>3</sup>).

### 3.5.2 First ratoon cane (2019/20 growing season)

1) Germination (%) was recorded at 1 MAH of the ratoon crop, the equation was modified from Chumphu et al. (2019), due to the time limit of 2 crops continually as followed by the equation (8)

$$\text{Germination (\%)} = \frac{\text{Number of stool germinated of the ratoon cane}}{\text{Number of stool harvested of the plant cane}} \times 100 \quad (8)$$

2) Growth parameters, yield, and yield components including plant height, number of stalks, yield, TSS, and stalk diameter were collected and measured as the same methods as the PC.

3) Ratooning ability (RA) was modified from the equation of Olaoye, (2008), due to this experiment was conducted with the time limit for two crops as the equation (9)

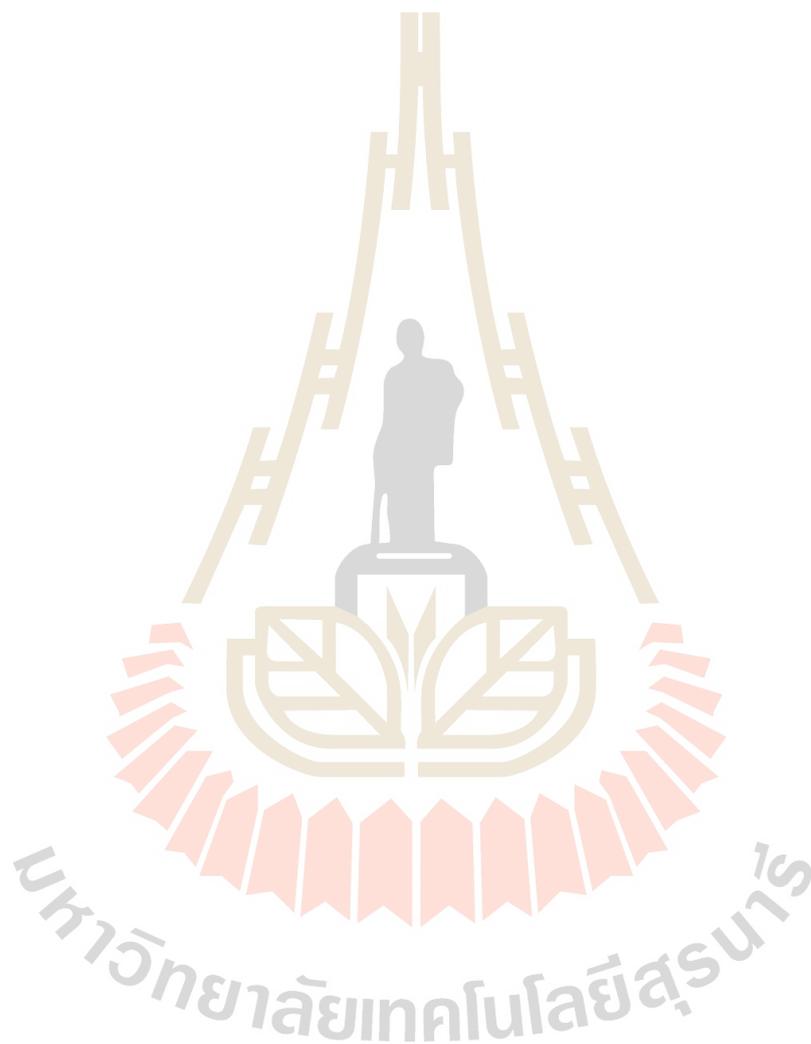
$$RA (\%) = \frac{RC_i}{PC} \times 100 \quad (9)$$

Where RA was a ratio of properties among ratoon crop and plant crop in percentage, RC is the yield of properties in ratoon crop, and PC is the yield of properties in PC.

4) Total RLD and RLD patterns were collected at 6 MAH with the same method as in PC.

### 3.6 Statistical analysis

All data were analyzed using General Linear Model (Agresti, 2014). In all analyses, mean values were compared using Duncan Multiple Range Test (DMRT), and the significant differences were tested at a p-value  $<0.05$ . The combined analysis was performed with two sites only for the PC data.



## CHAPTER IV

### RESULTS AND DISCUSSION

#### 4.1. Crop water requirement, rainfall, and irrigation consumption

The crop water requirement, rainfall, and irrigation water in PC (PC) are shown in Table 4.1 for sandy clay loam soil (SCL soil) and Table 4.2 for loamy sand soil (LS soil), and those of the 1<sup>st</sup> ratoon crop (FRC) are shown in Table 4.3 (SCL) and Table 4.4 (LS).

In SCL soil, the crop water requirements of all crop practices were similar in PC and FRC (about 1,200 mm) (Table 4.1 and Table 4.3). The rainfall and effective rain in FRC were higher than in the PC. Therefore, low effective rain established higher irrigated water in PC (1,140 mm) than in FRC (815 mm).

In LS soil, the crop water requirement in PC and FRC were similar to in SCL soil, the crop required about 1,200 mm of water (Table 4.2 and Table 4.4). The rainfall and effective rain were higher in PC (994 and 532 mm) than in FRC (591 and 315 mm). However, the actual amount of irrigation water was higher in PC (402 mm) than in FRC (342 mm) due to the inadequate water stock in FRC.

**Table 4.1** Crop water requirement, rainfall, and irrigation water in PC in SCL soil.

Month	Crop requirement (mm)	Rainfall (mm)	Effective rain (mm)	Irrigation (mm)
January	33.0	–	–	32.9
February	74.0	3.00	2.10	74.5
March	117	5.00	3.50	117
April	157	15.0	10.5	157
May	176	83.0	58.1	175
June	185	28.0	19.6	184
July	156	30.0	21.0	148
August	141	121	42.0	99.0
September	94	152	76.1	24.8
October	70.0	24.0	16.8	70.3
November	55.0	5.00	3.50	54.8
Total (mm)	1,258	466	253	1,140

**Table 4.2** Crop water requirement, rainfall, and irrigation water in PC in LS soil.

Month	Crop requirement (mm)	Rainfall (mm)	Effective rain (mm)	Irrigation (mm)
January	94.0	–	–	12.5
February	118.0	3.10	2.20	22.4
March	143.0	4.30	3.00	87.5
April	169.0	59.4	41.6	62.5
May	185.0	158	102	37.5
June	144.0	98.0	51.0	37.5
July	123.0	112	78.7	25.0
August	104.0	292	121	25.0
September	64.0	183	74.1	50.0
October	58.0	80.3	56.2	25.0
November	79.0	3.10	2.20	16.7
Total (mm)	1,281	994	532	402

**Table 4.3** Crop water requirement, rainfall, and irrigation water in FRC in SCL soil.

Month	Crop requirement (mm)	Rainfall (mm)	Effective rain (mm)	Irrigation (mm)
February	38.5	–	–	37.0
March	88.5	4.0	2.8	83.0
April	119.7	36.0	25.2	99.0
May	147.1	70.0	49.0	99.0
June	160.0	62.0	43.4	124.0
July	188.1	123.0	69.0	124.0
August	151.6	42.0	29.4	124.0
September	121.0	240.0	122.2	25.0
October	103.8	200.0	129.3	25.0
November	66.3	7.0	4.9	50.0
December	26.3	–	–	25.0
Total (mm)	1,211	784	475	815

**Table 4.4** Crop water requirement, rainfall and irrigation water in FRC in LS soil.

Month	Crop requirement (mm)	Rain fall (mm)	Effective rain (mm)	Irrigation (mm)
February	46.0	–	–	8.3
March	82.0	9.30	6.50	13.3
April	108	42.6	29.8	45.3
May	134	50.0	35.0	53.3
June	151	39.0	27.3	106.7
July	160	60.0	42.0	114.9
August	144	9.00	6.30	–
September	121	242	106	–
October	103	139	61.5	–
November	77.0	–	–	–
December	68.0	–	–	–
Total (mm)	1,236	591	315	342

## 4.2 First year experiment : Effects of fertilizer application and irrigation method on growth and yield of sugarcane.

### 4.2.1 Sugarcane growth parameters in PC

The sugarcane growth parameters including the number of shoots, plant height, leaf SPAD chlorophyll meter reading (leaf SCMR), and Leaf area index (LAI) were measured in both soil textures at 2, 4, and 6 month after planting (MAP).

#### 1) Number of shoots

The number of shoots in each soil texture is presented in Table 4.5 for SCL soil, Table 4.6 for LS soil, and Table 4.7 for soil texture and treatment combination.

In SCL soil, the treatments significantly affected the number of shoots, the highest number of shoots was found in T3 at 2, 4 and 6 MAP, (13,907, 24,093 and 14,722 shoots/rai) compared with T2 (10,722, 21,926 and 12,315 shoots/rai) and T1 (9,796, 16,907 and 11,500 shoots/rai), respectively.

**Table 4.5** Effects of irrigation and fertigation on the number of shoots in SCL soil.

Treatment	Number of shoots (shoots/rai)		
	2 MAP	4 MAP	6 MAP
T1: Rainfed condition	9,796 <sup>b</sup>	16,907 <sup>c</sup>	11,500 <sup>b</sup>
T2: Drip irrigation + soil fertilizer	10,722 <sup>b</sup>	21,926 <sup>b</sup>	12,315 <sup>b</sup>
T3: Drip fertigation	13,907 <sup>a</sup>	24,093 <sup>a</sup>	14,722 <sup>a</sup>
CV (%)	10.64	3.66	3.72

Means within the same column labeled with the same letters indicate statistically significant differences by DMRT at  $P < 0.05$ .

In LS soil, the highest number of shoots was found in T3 at 2, 4 and 6 MAP (18,574, 22,148 and 11,556 shoots/rai) compared with T2 (13,037, 18,222 and 10,963 shoots/rai) and T1 (11,648, 15,500 and 10,309 shoots/rai), respectively.

**Table 4.6** Effects of irrigation and fertigation on number of shoots in LS soil.

Treatment	Number of shoots (shoots/rai)		
	2 MAP	4 MAP	6 MAP
T1: Rainfed condition	11,648 <sup>b</sup>	15,500 <sup>b</sup>	10,309 <sup>b</sup>
T2: Drip irrigation + soil fertilizer	13,037 <sup>b</sup>	18,222 <sup>ab</sup>	10,963 <sup>ab</sup>
T3: Drip fertigation	18,574 <sup>a</sup>	22,148 <sup>a</sup>	11,556 <sup>a</sup>
CV (%)	13.92	14.14	3.95

Means within the same column labeled with the same letters indicate statistically significant differences by DMRT at  $P < 0.05$ .

The combined effects of site and treatment on number of shoots was evaluated. In general, the soil textures affected number of shoots i.e., the average number of shoot in SCL soil was higher (14,420, 20,975 and 12,846 shoot/rai) than in LS soil (11,474, 18,623 and 10,942 shoots/rai) at 2, 4 and 6 MAP, respectively. The average number of shoots was also significantly different among the treatments, T3 produced the highest number of shoots at 2, 4 and 6 MAP (16,241, 23,120 and 13,139 shoots/rai) compared with T2 (11,880, 20,074 and 11,639 shoots/rai) and T1 (10,722, 16,204 and 10,904 shoots/rai), respectively.

**Table 4.7** Combined effects of site and fertigation on the number of shoots.

Variable	Number of shoots (shoots/rai)		
	2 MAP	4 MAP	6 MAP
Site (A)	**	*	**
SCL soil	14,420 <sup>a</sup>	20,975 <sup>a</sup>	12,846 <sup>a</sup>
LS soil	11,474 <sup>b</sup>	18,623 <sup>b</sup>	10,942 <sup>b</sup>
Treatment (B)	**	**	**
T1: Rainfed condition	10,722 <sup>b</sup>	16,204 <sup>b</sup>	10,904 <sup>c</sup>
T2: Drip irrigation + soil fertilizer	11,880 <sup>b</sup>	20,074 <sup>a</sup>	11,639 <sup>b</sup>
T3: Drip fertigation	16,241 <sup>a</sup>	23,120 <sup>a</sup>	13,139 <sup>a</sup>
Site * Treatment	ns	ns	**
CV (%)	7.50	7.17	4.12

Means within the same column labeled with the same letters indicate statistically significant differences by DMRT at  $P < 0.05$ .

## 2) Plant height

The plant height in each soil texture is shown in Table 4.8 for SCL soil, Table 4.9 for LS soil, and Table 4.10 for soil texture and treatment combination. In SCL soil, the treatment significantly affected sugarcane height. The highest plant height at 2, 4, and 6 MAP was found in T3 (22.1, 96.5, and 163.9 cm) compared with T2 (16.4, 73.9, and 156.0 cm) and T1 (13.7, 46.2, and 89.9 cm), respectively.

**Table 4.8** Effects of irrigation and fertigation on plant height in SCL soil.

Treatment	Plant height (cm)		
	2 MAP	4 MAP	6 MAP
T1: Rainfed condition	13.7 <sup>c</sup>	46.2 <sup>c</sup>	89.9 <sup>b</sup>
T2: Drip irrigation + soil fertilizer	16.4 <sup>b</sup>	73.9 <sup>b</sup>	156.0 <sup>a</sup>
T3: Drip fertigation	22.1 <sup>a</sup>	96.5 <sup>a</sup>	163.9 <sup>a</sup>
CV (%)	6.71	7.45	4.83

Means within the same column labeled with the same letters indicate statistically significant differences by DMRT at  $P < 0.05$ .

In LS soil, the highest plant height at 2, 4, and 6 MAP was significantly different among the treatments, T3 produced the highest plant height (13.9, 37.5, and

176 cm) compared to T2 (12.0, 27.9, and 159 cm) and T1 (9.8, 19.1 and 114 cm), respectively.

**Table 4.9** Effects of irrigation and fertigation on plant height in LS soil.

Treatment	Plant height (cm)		
	2 MAP	4 MAP	6 MAP
T1: Rainfed condition	9.8 <sup>b</sup>	19.1 <sup>b</sup>	114 <sup>b</sup>
T2: Drip irrigation + soil fertilizer	12.0 <sup>ab</sup>	27.9 <sup>ab</sup>	159 <sup>a</sup>
T3: Drip fertigation	13.9 <sup>a</sup>	37.5 <sup>a</sup>	176 <sup>a</sup>
CV (%)	7.78	10.74	6.05

Means within the same column labeled with the same letters indicate statistically significant differences by DMRT at  $P < 0.05$ .

The combined effects of site (A) and treatments (B) on plant height was presented in Table 4.10. For soil texture (A), the plant height was significantly different between the soil textures. The plant height in SCL soil (17.4, 72.2, and 150 cm) was greater than in LS soil (11.9, 28.2, and 137 cm) at 2,4 and 6 MAP, respectively. For treatment (B), the treatments also significantly affected plant height, T3 produced the highest plant height at 2,4 and 6 MAP (17.9, 67.0, and 170 cm) compared with T2 (14.2, 50.9 and 157 cm) and T1 (11.7, 32.6 and 102 cm), respectively.

**Table 4.10** Combined effects of site and fertigation on plant height.

Variable	Plant height (cm)		
	2 MAP	4 MAP	6 MAP
Site (A)	**	**	*
SCL soil	17.4 <sup>a</sup>	72.2 <sup>a</sup>	150 <sup>a</sup>
LS soil	11.9 <sup>b</sup>	28.2 <sup>b</sup>	137 <sup>b</sup>
Treatment (B)	**	**	**
T1: Rainfed condition	11.7 <sup>c</sup>	32.6 <sup>c</sup>	102 <sup>b</sup>
T2: Drip irrigation + soil fertilizer	14.2 <sup>b</sup>	50.9 <sup>b</sup>	157 <sup>a</sup>
T3: Drip fertigation	17.9 <sup>a</sup>	67.0 <sup>a</sup>	170 <sup>a</sup>
Site * Treatment	*	**	ns
CV (%)	9.75	10.16	8.41

Means within the same column labeled with the same letters indicate statistically significant differences by DMRT at  $P < 0.05$ .

#### 4.2.2 LAI and leaf SCMR

LAI and leaf SCMR at 4 MAP in each soil texture are presented in Table 4.11 for SCL soil, Table 4.12 for LS soil, and Table 4.13 for soil texture and treatment combination.

In SCL soil, the sugarcane management significantly affected LAI and leaf SCMR. The highest LAI and leaf SCMR (6.11 and 44.7) at 4 MAP was produced in T3, compared with T2 (5.31 and 38.1) and T1 (2.62 and 34.2), respectively.

**Table 4.11** Effects of irrigation and fertigation on LAI and leaf SCMR at 4 MAP in SCL soil.

Treatment	LAI	Leaf SCMR (SPAD unit)
T1: Rainfed condition	2.62 <sup>b</sup>	34.2 <sup>c</sup>
T2: Drip irrigation + soil fertilizer	5.31 <sup>a</sup>	38.1 <sup>b</sup>
T3: Drip fertigation	6.11 <sup>a</sup>	44.7 <sup>a</sup>
CV (%)	11.03	2.72

Means within the same column labeled with the same letters indicate statistically significant differences by DMRT at  $P < 0.05$ .

In LS soil, the highest LAI and leaf SCMR 4 MAP were recorded in T3 (4.16 and 41.6) compared to T2 (2.95 and 39.2) and T1 (1.58 and 37.7), respectively. The similar result was found in SCL soil.

**Table 4.12** Effects of irrigation and fertigation on LAI and leaf SCMR at 4 MAP in LS soil.

Treatment	LAI	Leaf SCMR (SPAD unit)
T1: Rainfed condition	1.58 <sup>b</sup>	37.7 <sup>b</sup>
T2: Drip irrigation + soil fertilizer	2.95 <sup>a</sup>	39.2 <sup>ab</sup>
T3: Drip fertigation	4.16 <sup>a</sup>	41.6 <sup>a</sup>
F-test	**	*
CV (%)	9.52	3.42

Means within the same column labeled with the same letters indicate statistically significant differences by DMRT at  $P < 0.05$ .

The combination effects of site (A) and treatments (B) on LAI and leaf chlorophyll are presented in Table 4.13. For soil texture (A), the LAI was significantly different between the soil textures. The LAI at 4 MAP of SCL soil (4.50) was greater than of the LS soil (2.79). In contrast, the leaf SCMR was not affected by the soil textures. For treatment (B), the LAI and leaf chlorophyll were significantly different among the crop managements. The highest LAI and chlorophyll at 4 MAP were found in T3 (5.06 and 43.2) compared to T2 (4.04 and 38.7) and T1 (2.04 and 35.9), respectively.

**Table 4.13** Combined effects of site and fertigation on LAI and leaf SCMR.

Variable	LAI	Leaf SCMR (SPAD unit)
Site (A)	**	ns
SCL soil	4.50 <sup>a</sup>	39.0
LS soil	2.79 <sup>b</sup>	39.5
Treatment (B)	**	**
T1: Rainfed condition	2.04 <sup>c</sup>	35.9 <sup>c</sup>
T2: Drip irrigation + soil fertilizer	4.04 <sup>b</sup>	38.7 <sup>b</sup>
T3: Drip fertigation	5.06 <sup>a</sup>	43.2 <sup>a</sup>
Site * Treatment	ns	**
CV (%)	9.48	3.11

Means within the same column labeled with the same letters indicate statistically significant differences by DMRT at  $P < 0.05$ .

The overall results found that, in the irrigated treatments (T2 and T3), all growth parameters including plant height, shoot numbers, LAI and leaf SCMR were significantly higher than in the rainfed practice (T1) in both soils.

The LAI are important growth parameters as they are directly related to photosynthesis. LAI value means light-receiving area in the plant which relates to the rate of photosynthesis. In this study, the result showed that the rainfed treatments in both locations (SCL and LS soil) which faced high risk of water stress had the less LAI than the drip irrigation treatments since the water stress was the cause of reduction in leaf expansion and tiller production.

The findings was in agreement with Yadav and Prasad (1988) who studied the responses of three sugarcane genotypes to water application and found that the LAI was greater in the well irrigated condition, and it decreased significantly with the water stress condition. Similarly, Begum et al. (2012) studied 6 different genotypes of sugarcane under 4 watering methods and found that the highest LAI decline was found in water stress condition. (Kawakami et al., 2006) also demonstrated that water stress caused an inhibiting leaf area of plants.

The SPAD chlorophyll meter reading (SCMR) was a tool which used for measuring leaf chlorophyll and indirectly assessing to leaf nitrogen status. Htoon et al.(2019) and Richardson et al. (2002) found that the SCMR was closely related to chlorophyll content and chlorophyll density. In this study, the results showed that rainfed conditions at high risk of drought stress had less SCMR than the drip irrigation treatments, as drought stress was a major factor in reducing chlorophyll activity, photosynthesis rate and growth. A similar study by Chumphu et al. (2019) found that the sugarcane had less SCMR than water sufficient condition in drought stress condition. Jangpromma et al. (2012) found that in 4 sugarcane cultivar, the leaf chlorophyll was reduced by drought stress condition more than water sufficient condition.

The reduction in LAI and SCMR under rainfed treatment was positively related to the reduction in shoot population and plant height in sugarcane production. A similar result was reported by Radhamani et al. (2015) who demonstrated that the leaf SCMR had significantly correlated to leaf chlorophyll content, yield, and number of millablecane (NMC) of sugarcane. Khonghintaisong et al. (2017) found that the increase of leaf SCMR was positively correlated with the daily plant height increasing, it also positively correlated to stalk production.

The overall results are in agreement of other studies such as Wonprasaid and Girdthai (2014) who reported that the irrigation treatments established higher germination and growth than no irrigation treatment. Under limited water supply (no irrigation practice) sugar cane growth was limited by reducing the length of internode, stalk germination, and biomass accumulation (Jangpromma et al., 2012 and Khonghintaisong et al., 2017).

The effect of fertilizer on sugarcane growth was related to irrigation or cultural practice. The results showed that among drip irrigation treatments, fertigation (T3) exhibited higher sugarcane growth than the soil application treatment (T2). As the soil application is a solid form of fertilizer applied, it is low efficient due to many factors such as absorbing by the soil particle, washing by the heavy rain, and vaporizing. Moreover, for the soil application, fertilizer is applied twice due to the limited labor cost, whereas for fertigation, fertilizer can be applied several times. Therefore, the fertilizer with fertigation was more uniform with less concentration at the plant root zone compared to soil application which reduced the risk of nutrient loss, especially N fertilizer (Shedeed et al., 2009).

For soil texture, the soil environment is one of major the factors affecting sugarcane growth and yield. This study founded that the SCL was better than LS soil regarding sugarcane performance. The chemical composition and physical properties of different soils affect the nutrient uptake of the plant (Begum et al., 2016). In this study, SCL was soil with higher fertility soil compared to LS soil. Moreover, SCL soil had higher water holding capacity resulting in better water and nutrient holding which consequently caused less water and nutrient loss when compared to LS (Johnston and Bruulsema, 2014).

#### **4.2.3 Leaf tissue nutrient of sugarcane**

Leaf nutrient analysis is shown in Table 4.14 for SCL soil and Table 4.15 for LS soil. In SCL soil, leaf N, K and Mg were significantly different, while P and Ca were not significantly different among the treatments. The highest N and K content in leaf tissue was found in T3 but the highest Mg content was found in T1.

In LS soil, all leaf nutrients had not significantly different among treatments.

**Table 4.14** Effects of irrigation and fertigation on leaf nutrients in SCL soil at 6 MAP.

Treatments	Nutrient content (%)				
	N	P	K	Ca	Mg
T1	1.14 <sup>b</sup>	0.147	1.20 <sup>b</sup>	0.773	0.253 <sup>a</sup>
T2	1.20 <sup>ab</sup>	0.158	1.40 <sup>ab</sup>	0.800	0.195 <sup>ab</sup>
T3	1.27 <sup>a</sup>	0.141	1.68 <sup>a</sup>	0.648	0.113 <sup>b</sup>
Sufficient level (%)	2.00–2.60	0.22–0.30	1.00–1.60	0.22–0.45	0.15–0.32
CV (%)	6.24	11.48	15.20	13.58	30.17

Means within the same column labeled with the same letters indicate statistically significant differences by DMRT at  $P < 0.05$ .

**Table 4.15** Effects of irrigation and fertigation on leaf nutrients in LS soil at 6 MAP.

Treatments	Nutrient (%)				
	N	P	K	Ca	Mg
T1	1.45	0.127	1.22	1.29	0.780
T2	1.43	0.111	1.09	1.09	0.708
T3	1.37	0.116	1.04	1.09	0.715
Sufficient level (%)	2.00–2.60	0.22–0.30	1.00–1.60	0.22–0.45	0.15–0.32
CV (%)	3.88	7.88	16.69	12.34	13.77

Means within the same column labeled with the same letters indicate statistically significant differences by DMRT at  $P < 0.05$ .

The result of nutrient analysis established a significant difference between soil textures. In SCL soil, N and K content increased by drip irrigation treatments (T2 and T3) compared to the rainfed treatment (T1). Comparing between fertilizer application treatments, the leaf N and K tended to be higher in fertigation than in soil application treatment. In contrast, the Mg content showed the opposite trend, while P and Ca were not significantly different among the treatments. In LS soil, all of the nutrients were not different among the treatments. Even though the nutrient contents were not significantly different among the treatments, the total nutrients uptake would be higher in the irrigation treatments as they had more biomass than the rainfed treatment (predict from the yield and yield component) (Table 4.17).

In SCL soil, the higher leaf N and K contents in fertigation treatment (T3) than in soil application treatments (T1 and T2) indicated more N and K uptake under fertigation. More N and K uptake in fertigation was probably due to N and K fertilizer was readily dissolved and immediately uptake by the roots. While in the soil application treatments, N and K were in the solid form of fertilizer which was hardly dissolved in the soils with low or uneven moisture under rainfed and drip irrigation in the normal conditions. When there is too heavy rain, N and K are also easily loss by deep percolation. The results were similar to other researches such as Sinworn (2014) and (Xie, 2018) who reported that cassava leaf N and K concentration under fertigation was higher than under soil application.

Leaf tissue nutrients of sugarcane in this study were lower than the sufficient levels reported by Anderson and Bowen (1990) and McCray et al. (unpublished) who studied and recommended in Louisiana, USA. The lower leaf nutrients in this study were probably due to the differences in sugar cane varieties and environments.

#### **4.2.4 Yield and yield components**

Yield and yield components at 12 MAP are shown in Table 4.16 for SCL soil, Table 4.17 for LS soil, and Table 4.18 for site and treatment combination.

In SCL soil, the treatments significantly affected the sugarcane yield and yield components. NMC, plant height, and cane yield of T3 were the highest (14,667 canes/rai, 299 cm, and 27.6 tons/rai) and those of T1 were the lowest (11,056 canes/rai, 191 cm, and 15.5 tons/rai), respectively. While the cane diameter showed the opposite result i.e. the cane diameter of T1 was the highest (27.8 mm) and T3 was the lowest (25.0 mm), respectively. The total soluble solid (TSS) was not significantly different among treatments

**Table 4.16** Effects of irrigation and fertigation on yield and yield components at 12 MAP in SCL soil.

Treatment	NMC (canes/rai)	Plant height (cm)	Cane diameter (mm)	Yield (tons/rai)	TSS (°Brix)
T1	11,056 <sup>c</sup>	191 <sup>c</sup>	27.8 <sup>a</sup>	15.5 <sup>c</sup>	22.3
T2	12,204 <sup>b</sup>	265 <sup>b</sup>	27.0 <sup>a</sup>	21.5 <sup>b</sup>	22.5
T3	14,667 <sup>a</sup>	299 <sup>a</sup>	25.0 <sup>b</sup>	27.6 <sup>a</sup>	22.8
CV (%)	3.06	5.76	2.56	4.61	2.26

Means within the same column labeled with the same letters indicate statistically significant differences by DMRT at  $P < 0.05$ .

In LS soil, NMC, plant height, and cane yield were significantly different among treatments (Table 4.17). T3 showed the highest values of NMC, plant height and yield (11,037 canes/rai, 316 cm and 17.3 tons/rai) compared with T2 (10,148 canes/rai, 299 cm and 16.2 tons/rai) and T1 (9,432 canes/rai, 246 cm and 12.5 tons/rai), respectively. While the cane diameter and TSS were not affected by the irrigation and fertigation.

**Table 4.17** Effects of irrigation and fertigation on yield and yield components at 12 MAP in LS soil.

Treatment	NMC (canes/rai)	Plant height (cm)	Cane diameter (mm)	Yield (tons/rai)	TSS (°Brix)
T1	9,432 <sup>b</sup>	246 <sup>b</sup>	29.9	12.5 <sup>b</sup>	20.3
T2	10,148 <sup>ab</sup>	299 <sup>a</sup>	27.8	16.2 <sup>a</sup>	21.5
T3	11,037 <sup>a</sup>	316 <sup>a</sup>	26.9	17.3 <sup>a</sup>	21.4
CV (%)	5.55	4.93	4.88	11.11	6.27

Means within the same column labeled with the same letters indicate statistically significant differences by DMRT at  $P < 0.05$ .

The site and treatment combined analysis (Table 4.18) indicated that cane yield (20.4 ton/rai), NMC (12,919 stalk/rai) plant height (287 cm), and brix (22.5 %) in SCL

soil were higher than in LS soil. However, the cane diameter in LS (28.2 mm) was higher than in SCL soil. While the highest yield (22.4 tons/rai), the NMC (12,898 stalk/rai) plant height (308, 282), and brix (22.5%) were found in drip fertigation treatment (T3) and the lowest was in rainfed treatment (T1). Whereas the highest cane diameter (28.9 mm) was exhibited in the rainfed treatment (T1) and the brix was not significantly different among the treatments.

For the combination effects on yield and yield component in PC, the interaction of yield is shown in Fig. 4.1. For site, SCL had greater yield than in LS soil. For treatments, well irrigated practices (T2 and T3) had not significantly different on yield in LS soil, but 2 in SCL, T3 tended to produce more yield than T2 and T1, respectively.

The interaction effect of plant height is shown in Fig 4.2. For site, well irrigated treatments in LS (T2 and T3) had not significantly different in plant height, but in SCL T3 had higher plant height than T2 and T1, respectively. However, the result of plant height in both site (SCL and LS soil) showed that T3 tended to have the highest plant height while T1 tended to have the lowest.

The interaction effect of NMC is shown in Fig 4.3. For site, NMC was produced in SCL soil more than in LS soil. However, the treatments in both site affected the similar result, NMC was produced in T3 more than in T2 and T1, respectively.

**Table 4.18** The interaction effects of site and fertigation on yield and components.

Variable	NMC (canes/rai)	Plant height (cm)	Cane diameter (mm)	Yield (tons/rai)	TSS (°Brix)
Site (A)	**	**	*	**	*
SCL soil	12,919 <sup>a</sup>	252 <sup>b</sup>	2.67 <sup>b</sup>	20.4 <sup>a</sup>	22.5 <sup>a</sup>
LS soil	9,897 <sup>b</sup>	287 <sup>a</sup>	2.82 <sup>a</sup>	15.4 <sup>b</sup>	21.8 <sup>b</sup>
Treatment (B)	**	**	*	**	ns
T1	10,243 <sup>c</sup>	218 <sup>c</sup>	2.89 <sup>a</sup>	13.1 <sup>c</sup>	22.0
T2	11,083 <sup>b</sup>	282 <sup>b</sup>	2.74 <sup>ab</sup>	18.3 <sup>b</sup>	22.2
T3	12,898 <sup>a</sup>	308 <sup>a</sup>	2.60 <sup>b</sup>	22.4 <sup>a</sup>	22.3
Site * Treatment	**	*	ns	**	ns
CV (%)	5.21	2.94	5.81	7.70	3.03

Means within the same column labeled with the same letters indicate statistically significant differences by DMRT at  $P < 0.05$

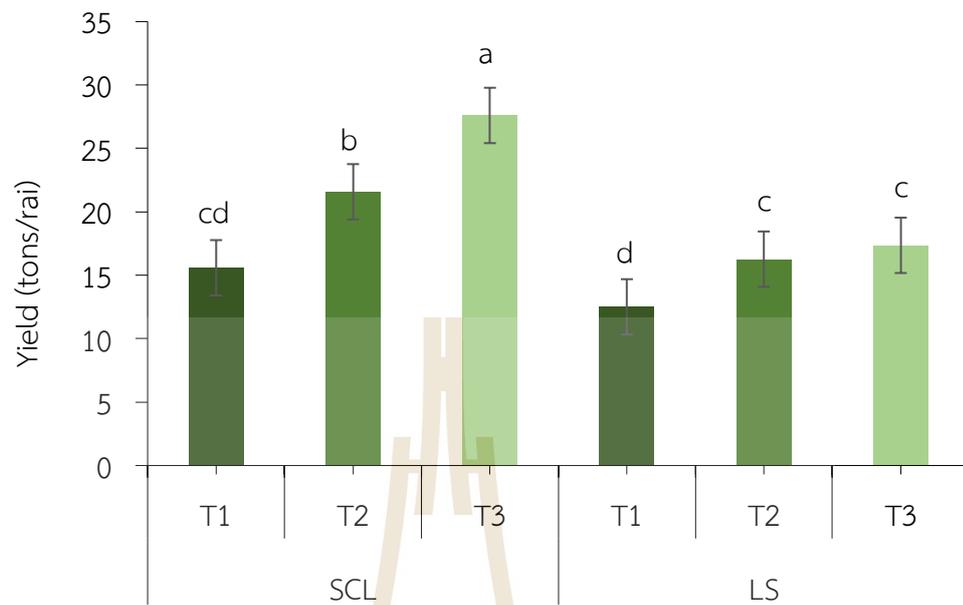


Figure 4.1 Interaction effects of site and fertigation on yield.

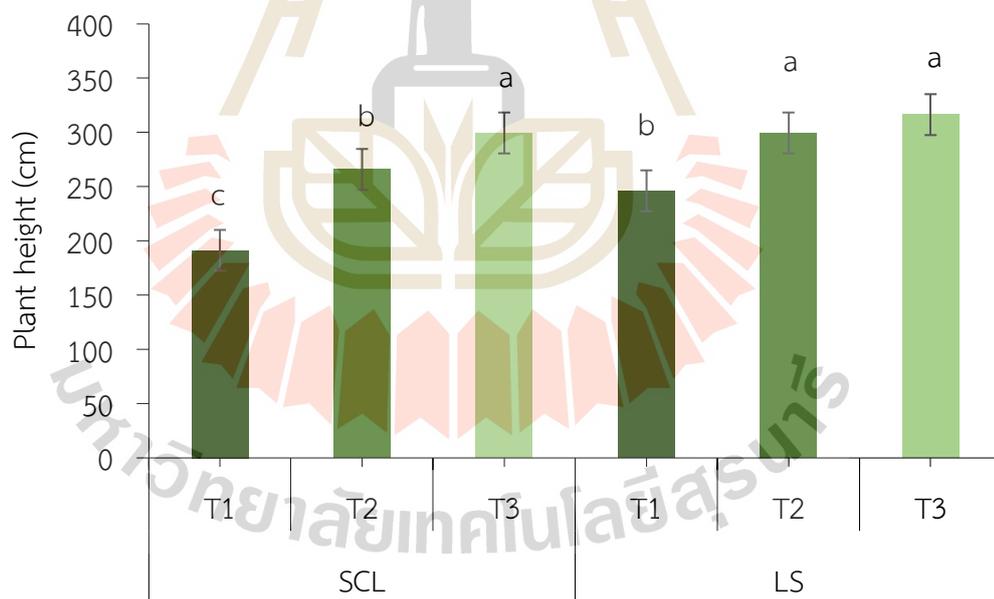
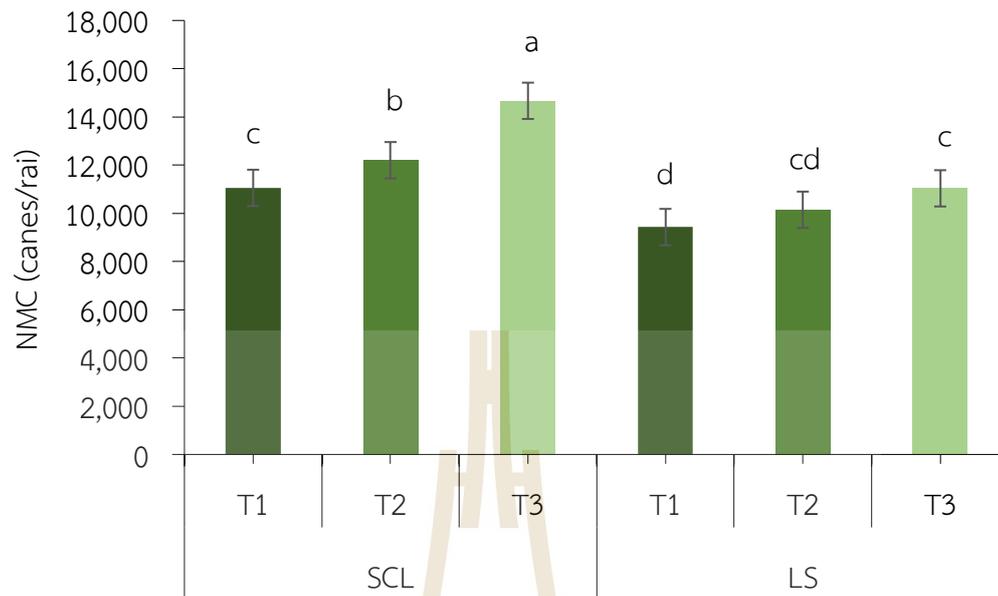


Figure 4.2 Interaction effects of site and fertigation on plant height.



**Figure 4.3** Interaction effects of site and fertigation on the NMC.

The results of yield and yield components in both soils were shown in the same direction i.e., yield and yield components in the drip irrigation treatments (T2 and T3) were higher than the rainfed practice (T1). As the drip-irrigated crop received water to meet the crop water requirement resulting to higher growth rate than the rainfed sugarcane (see the result of sugarcane growth parameter). In addition, drip irrigation also improved soil nutrient availability and increase crop nutrient uptake. The result was similar to other studies such as Wonprasaid and Girdthai (2014) who studied long term effects of irrigation on sugarcane production and found that irrigation improved the yield and yield components in sugarcane compared to the rainfed practice. Moreover, they reported that the irrigation treatment improved the ratooning periods more than 5 crops compared to 3 crops in the rainfed practice. Thong-ob (2013) who studied the effects of irrigation on cassava and found that non irrigated cassava established lower growths, yield, and yield components than irrigated treatment. In his experiment, the yield of cassava increased from 3.78 kg/plant in non-irrigated cassava to 6.40 kg/plant in irrigated cassava. The results were also supported by other studies such as Wiedenfeld and Enciso (2008) who found that the biomass of sugarcane increased when the water was sufficient and Rodrigues et al. (2009) who reported that the deficit condition

caused the reduction in the productivity of sugarcane including growth, yield, and quality. In addition, Khonghintaisong et al. (2017) reported that the water stress condition reduced the stomatal conductance and relative water content in the leaf which resulted to the reduction of biomass accumulation and yield.

Comparing between the drip irrigation treatments, it was found that the drip fertigation (T3) established higher yield and yield components than the soil application (T2 and T1). In fertigation, soluble fertilizer is normally applied several times with the low fertilizer concentration and directly to the root zone. This practice can prevent fertilizer loss due to deep percolation (under heavy rain) and fixation by soil particles and other minerals. In this study, in fertigation, fertilizer was equally applied 7 time during 1 MAP to 5 MAP, while in soil application, fertilizer was applied two times at 1 and 3 MAP. The more application frequency was the lower concentration of fertilizer which results to low chance of fertilizer loss from deep percolation and fixation. Moreover, the readily soluble nutrients under fertigation promotes the rate of nutrient uptake by sugarcane roots while the solid fertilizer application, nutrient uptake is dependent on the availability of soil water.

#### 4.2.5 Irrigation water use efficiency (IWUE).

The IWUE was not significantly affected by the irrigation practices in LS soil, but T3 tended to have higher IWUE than T2. While in SCL soil, T3 produce higher IWUE (0.015 tons/m<sup>3</sup>) than in T2 (0.012 tons/m<sup>3</sup>) (Table 4.19).

**Table 4.19** Effects of irrigation and fertigation on IWUE of sugarcane.

Source of variations	IWUE (tons/m <sup>3</sup> )	
	LS soil	SCL soil
T1: Rainfed condition	–	–
T2: Drip irrigation + soil fertilizer	0.025	0.012 <sup>b</sup>
T3: Drip fertigation	0.027	0.015 <sup>a</sup>
T-test	ns	**

Means within the same column labeled with the same letters indicate statistically significant differences with paired sample T-test.

#### 4.2.6 Fertilizer nutrient use efficiency (FNUE).

FNUE including N, P, and K at 12 MAP of SCL, and LS soils are shown in Tables 4.20 and 4.21, respectively, and the combined effects are in Table 4.22.

In SCL soil, the treatments significantly affected FNUE. T3 produced the highest N, P, and K use efficiency (1.69, 2.26, and 1.09 tons/kg) compared with T2 (1.26, 1.69, and 0.81 tons/kg) and T1 (0.85, 1.14, and 0.55 tons/kg), respectively.

**Table 4.20** Effects of irrigation and fertigation on FNUE at 12 MAP in SCL soil.

Treatment	FNUE (tons/kg)		
	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O
T1: Rainfed condition	0.85 <sup>c</sup>	1.14 <sup>c</sup>	0.55 <sup>c</sup>
T2: Drip irrigation + soil fertilizer	1.26 <sup>b</sup>	1.69 <sup>b</sup>	0.81 <sup>b</sup>
T3: Drip fertigation	1.69 <sup>a</sup>	2.26 <sup>a</sup>	1.09 <sup>a</sup>
CV (%)	6.45	6.45	6.45

Means within the same column labeled with the same letters indicate statistically significant differences by DMRT at  $P < 0.05$ .

In LS soil, the FNUE was also significantly different among the treatments, T3 produced the highest N, P and K use efficiency (0.80, 1.09 and 0.50 tons/kg) compared with T2 (0.74, 1.01 and 0.47 tons/kg) and T1 (0.57, 0.78 and 0.36 tons/kg), respectively.

**Table 4.21** Effects of irrigation and fertigation on FNUE at 12 MAP in LS soil.

Treatment	FNUE (tons/kg)		
	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O
T1: Rainfed condition	0.570 <sup>b</sup>	0.78 <sup>b</sup>	0.360 <sup>b</sup>
T2: Drip irrigation + soil fertilizer	0.740 <sup>a</sup>	1.01 <sup>a</sup>	0.470 <sup>a</sup>
T3: Drip fertigation	0.800 <sup>a</sup>	1.09 <sup>a</sup>	0.500 <sup>a</sup>
CV (%)	11.11	11.11	11.11

Means within the same column labeled with the same letters indicate statistically significant differences by DMRT at  $P < 0.05$ .

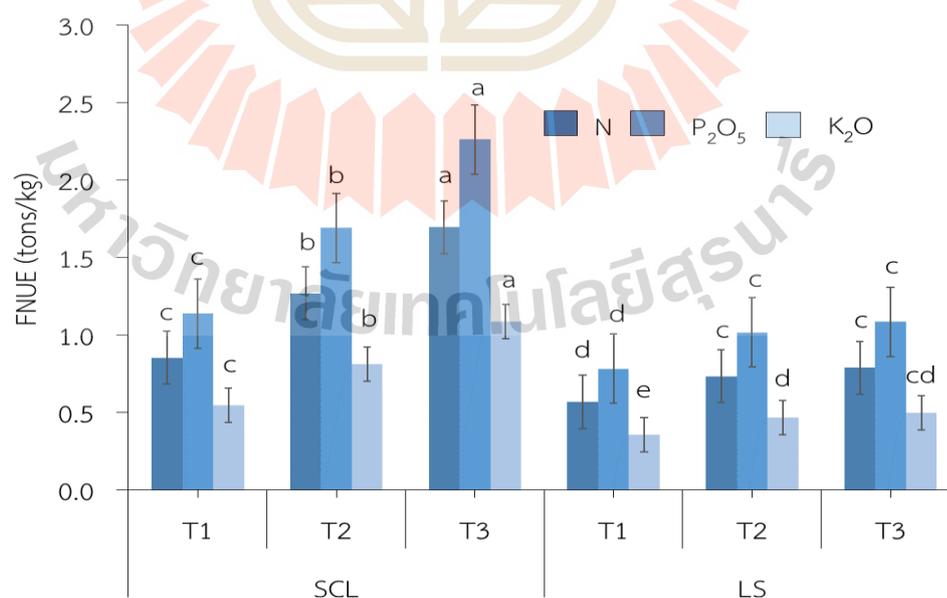
For interaction effects, it had an interaction between site (A) and treatments (B) on FNUE including N, P and K. For site (A), SCL soil had higher FNUE (N,

P and K) in all treatment than in LS soil. However, among the fertilizer applications, the fertigation (T3) in both site which applied the same rate of fertilizer and the same irrigation practice tended to have higher FNUE than the soil fertilizer application (T2) and rainfed condition (T1), respectively (Fig 4.4).

**Table 4.22** The interaction effects of site and treatments on FNUE of sugarcane.

Variable	FNUE (tons/kg)		
	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O
Site (A)	**	**	**
LS soil	0.699 <sup>b</sup>	0.962 <sup>b</sup>	0.440 <sup>b</sup>
SCL soil	1.270 <sup>a</sup>	1.690 <sup>a</sup>	0.814 <sup>a</sup>
Treatment (B)	**	**	**
T1: Rainfed condition	0.711 <sup>c</sup>	0.960 <sup>c</sup>	0.452 <sup>c</sup>
T2: Drip irrigation + soil fertilizer	1.000 <sup>b</sup>	1.354 <sup>b</sup>	0.639 <sup>b</sup>
T3: Drip fertigation	1.243 <sup>a</sup>	1.674 <sup>a</sup>	0.791 <sup>a</sup>
Site * Treatment	**	**	**
CV (%)	7.32	7.35	7.31

Means within the same column labeled with the same letters indicate statistically significant differences by DMRT at  $P < 0.05$ .



**Figure 4.4** Interaction effects of site and fertigation on FNUEs.

For IWUE, it was calculated only in the drip irrigation treatments (T2 and T3). In both soils, the drip fertigation (T3) had higher IWUE than soil fertilizer application (T2). As mentioned earlier, fertigation is more efficient for crop uptake, uniform distribution, and less loss than soil application. Therefore, fertigation promoted growth and yield of sugarcane which directly improve water use efficiency. The result agreed with a previous study by Hatfield and Dold (2019) who found the increase of yield which related to increase carbon structure was the key to improve IWUE. The same study also found that drip fertigation which had the highest yields, had a greater increase in IWUE than drip irrigation and surface irrigation with soil fertilizer application. A study of Quaggio et al. (2006) found that drip fertigation could increase the water efficiency by 13% higher than the same drip irrigation with soil fertilizer application

For FNUE, in both soils textures, the drip fertigation (T3) had the highest FNUE, while the rainfed condition had the lowest FNUE. As mentioned earlier, sugarcane yield was promoted by irrigation and fertigation and all treatments were applied with the same amount of fertilizer, therefore the FNUE was improved by irrigation and fertigation as it was calculated from yield per amount of fertilizer application. The results were similar to Kolange et al. (2001) and Pawar et al. (2013) who found that the drip fertigation increased the FNUE by 40 % compared to soil fertilizer application

#### **4.2.7 Underground stubble fresh and dry weight in SCL soil.**

The underground stubble weight (Table 4.23) showed that the irrigation treatments significantly affected the stubble dry and fresh weight. The rainfed treatment (T1) had the highest stubble weight (720 and 338 kg/rai for fresh and dry weight, respectively), while the irrigation treatments (T2 and T3) produced the lowest fresh and dry stubble weight.

**Table 4.23** Effects of irrigation and fertigation on Underground stubble weight in SCL soil at 12 MAP.

Treatment	Underground stubble weight (kg/rai)	
	Fresh weight	Dry weight
T1: Rainfed condition	720 <sup>a</sup>	351 <sup>a</sup>
T2: Drip irrigation + soil fertilizer	638 <sup>bc</sup>	305 <sup>b</sup>
T3: Drip fertigation	618 <sup>c</sup>	292 <sup>c</sup>
CV (%)	8.44	8.47

Means within the same column labeled with the same letters indicate statistically significant differences by DMRT at  $P < 0.05$ .

#### 4.2.8 Total root length density (Total RLD) and RLD pattern in SCL soil.

The result Total RLD is shown in Table 4.24. At upper soil layers (0–20 cm depth), the drip fertigation treatments (T3) produced higher total RLD (0.243 cm/cm<sup>3</sup>) than the drip irrigation with soil fertilizer (T2) (0.222 cm/cm<sup>3</sup>) and the rainfed treatment (T1) (0.213 cm/cm<sup>3</sup>). At middle soil layers (21–40 cm depth), the TRL was not influenced by the treatments. While at deep layers (41–80 cm depth), rainfed practice (T1) produced the highest total RLD (0.0244 cm/cm<sup>3</sup>) while well irrigated treatments (T2 and T3) had the lowest.

**Table 4.24** Effects of irrigation and fertigation on Total RLD in PC in SCL soil at 12 MAP.

Treatment / Depth	Total RLD (cm/cm <sup>3</sup> )		
	0–20 cm	21–40 cm	41–80 cm
T1: Rainfed condition	0.213 <sup>b</sup>	0.0579	0.0244 <sup>a</sup>
T2: Drip irrigation + soil fertilizer	0.222 <sup>ab</sup>	0.0595	0.0182 <sup>b</sup>
T3: Drip fertigation	0.243 <sup>a</sup>	0.0485	0.0203 <sup>b</sup>
F-test	**	ns	*
CV (%)	8.07	13.90	14.90

Means within the same column labeled with the same letters indicate statistically significant differences by DMRT at  $P < 0.05$ .

The RLD pattern is shown in Fig 4.5. At the upper soil layers (0–20 cm depth), the rainfed treatment (T1) tended to produce higher RLD close to planting row than the irrigation treatments (T2 and T3). In contrast, in the further distance

from planting row (40–80 cm), the irrigation treatments tended to produce higher RLD than the rainfed treatment. The highest total RLD value was also found in the rainfed treatment (1.247 cm/cm<sup>3</sup>). At the middle layer (21–40 cm depth), the rainfed practice also produced higher RLD close to the planting row than the irrigation treatments (T2 and T3). At the deep soil layer (41–80 cm depth), the rainfed treatment tended to produce higher RLD than the irrigation treatments (T2 and T3).

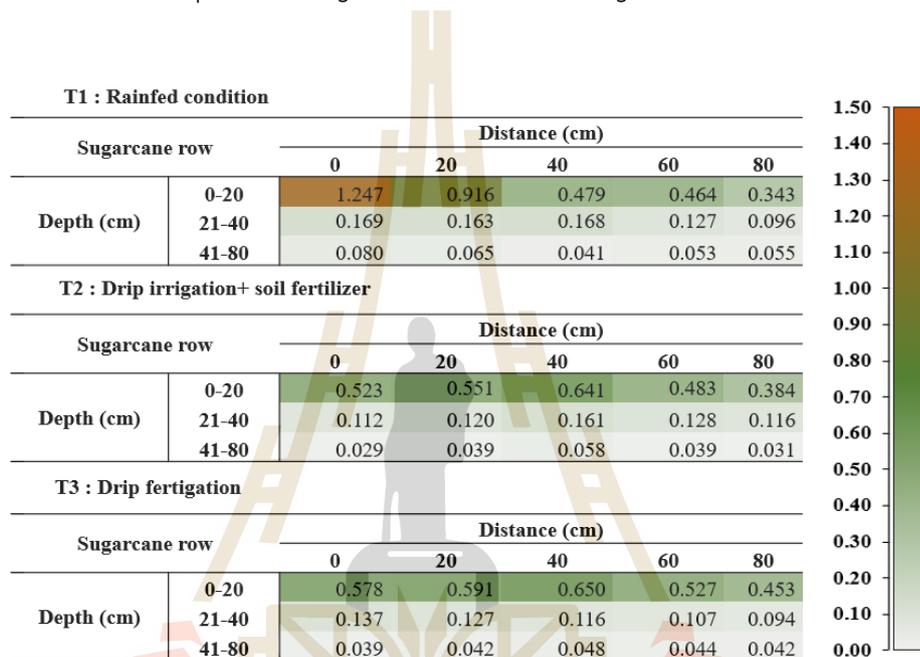


Figure 4.5 Effects of irrigation and fertigation on RLD pattern (cm/cm<sup>3</sup>) in SCL soil.

From the result, the underground structure including stubble weight, Total RLD, and RLD pattern were affected by the sugarcane practices. The underground stubble (fresh and dry weight) was the highest in the rainfed treatment. However, the underground stubble of sugarcane and its effects on ratooning have not been extensively studied. In general, the large stubble creation is related to the reserved energy for root growth and root avoidance from drought stress. Blum (2005) and Kooyers (2015) reported that one process of sugarcane adapted to drought stress was to maintain water uptake by increasing absorption root area. Basu et al. (2016) and Wasaya et al. (2018) reviewed that the character of roots can indicate drought adaptability of sugarcane and the root distribution pattern is especially important for drought tolerance. In addition, Smith et al. (2005) suggested that drought tolerance

sugarcane cultivars tended to develop deep root systems and Songsri et al. (2009) reported that large root systems related to high WUE in drought conditions. Besides the result of underground stubble, the RLD result was similarly affected by irrigation treatments i.e. large stubble creation positively correlated to RLD of sugarcane in all soil depths (upper, middle, and deep soil) with the correlation value ( $r$ ) of 0.666, 0.529, and 0.662 respectively (Table 4.35). Rainfed practice tended to produce RLD close to planting row and deep soil layer more than both of drip irrigation treatments. The result was similar to Namwongsa et al. (2018) who reported that when sugarcane faced the drought stress and was rewatered, the deep root was induced more than non-stress condition. While Chumphu (2019) reported that under sufficient water conditions, the RLD was mostly distributed in upper soil layer. According to the report of Wiangnon et al. (2021) who studied the effects of drought stress and rewatering period in 13 sugarcane cultivars, they found that the root density of sugarcane related to the availability of soil water in which if the effective soil water changed, root distribution pattern would positively respond.

For Total RLD, the result showed that irrigation treatments produced higher total RLD than rainfed treatment. High root production was positively related to the biomass and yield production. The result was similar to the study of Wiangnon et al. (2021), who reported that high TRL was positively correlated with the biomass accumulation since high root production resulted to maintaining a high state of water and nutrient in leaf. Jangpromma et al. (2012) supported that the sugarcane cultivar with high WUE was positively correlated to high biomass accumulation and then high yield production as well. This result of this experiment was in agreement of these previous studies in which drip fertigation produced the highest TRL, had the highest cane yield and the highest IWUE and FNUE.

### **4.3 Second year experiment: Effects of Drip Fertigation on Growth, Yield, and Ratooning Ability of Sugarcane**

#### **4.3.1 The FRC germination (%)**

The FRC germination at 1 Month after harvest (MAH) is shown in Table 4.25. The residual crop practices (A) significantly affected FRC germination in SCL soil but not in LS soil. In SCL soil,

Rainfed residual (M1) had the highest FRC germination (256 %) while the drip fertigation residuals (M3) had the lowest FRC germination (200 %). In LS soil, the residual practice had no significant effect on FRC germination, but it showed the similar result as in SCL soil i.e., rainfed residual (M1) tended to have the higher germination in FRC than both drip irrigation residuals (M2 and M3).

In terms of the current crop practice (B), the results were similar in both site (SCL and LS soil). the current crop practice had no significantly effect on FRC germination. However, the drip fertigation practice (S2) in FRC tended to have higher germination than rainfed condition (S1).

**Table 4.25** Effects of PC residual management and FRC management on germination (%)

Source	Germination (%)	
	SCL soil	LS soil
Crop practice in PC (A)	**	ns
M1: Rainfed condition	256 <sup>a</sup>	140
M2: Drip irrigation + soil fertilizer	230 <sup>b</sup>	138
M3: Drip fertigation	200 <sup>b</sup>	132
Crop practice in FRC (B)	ns	ns
S1: Rainfed condition	217	135
S2: Drip fertigation	240	139
A*B	ns	ns
CV (%)	15.00	11.30

Means within the same column labeled with the same letters indicate statistically significant differences by DMRT at  $P < 0.05$ .

In the FRC, the result indicated that the germination was mainly affected by PC residual effects. The current crop practice seemed to have lower effect on FRC germination than the previous crop practice. The rainfed practice of previous crop which produced the highest underground structures in PC had the highest germination of FRC. As the underground structures are the stock of carbohydrate and energy, they are important for new root and shoot creation in ratoon cane (Xu et al., 2021). The results were similar to the study of Smith et al.

(2005) who reported that the residual root and stubble after harvest were the essential structures for supporting the shoot germination in ratoon crop. Even though, this study did not clearly explain the relationship between underground structure and FRC germination, the study of Pissolato et al. (2021) indicated that high underground structures production was positively related to the carbohydrate accumulation and the carbohydrate in root of the previous crop could induce the vigor of shoot of the current ratoon crop. Moreover, this study also found that RLD in the upper soil layer of PC residual positively affected the germination of FRC. This result was similar to the study of Chumphu et al. (2019) who reported that the high RLD at the harvest stage resulted to high germination percentage in the next ratoon crop. For the current crop practice in FRC, drip fertigation tended to have higher percentage of germination than the rainfed condition which related to the higher soil moisture content in the fertigation treatment. A Similar result was found by Pierre et al. (2014) who reported that soil moisture content at  $-0.5$  MPa which closed to FC point was suitable for cane germination.

#### 4.3.2 Sugarcane growth parameters in FRC

##### 1) Number of shoots

The number of shoots in FRC are shown in Table 4.26 for SCL soil and Table 4.27 for LS soil.

In SCL soil, the residual practices (A) had no significant effect on number of shoots in FRC at all MAH but the current crop practice (B) was the main factor to effect significantly on the number of shoots in FRC, drip fertigation practice (S2) had the highest number of shoot at 2, 4, and 6 MAH (38,395, 19,235, and 17,794 shoot/rai, respectively). while the rainfed condition had the lowest number of shoots at 2,4 and 6 MAH (28,041, 16,099, and 16,510 shoots/rai)

**Table 4.26** Effects of PC residual management and FRC management on number of shoots at 2, 4, and 6 MAH in SCL soil.

Source	Number of shoots (shoots/rai)		
	2 MAH	4 MAH	6 MAH
Crop practice in PC (A)	ns	ns	ns
M1: Rainfed condition	34,049	17,790	17,679
M2: Drip irrigation + soil fertilizer	32,716	18,469	16,667
M3: Drip fertigation	32,889	16,741	17,111
Crop practice in FRC (B)	**	**	*
S1: Rainfed condition	28,041 <sup>b</sup>	16,099 <sup>b</sup>	16,510 <sup>b</sup>
S2: Drip fertigation	38,395 <sup>a</sup>	19,235 <sup>a</sup>	17,794 <sup>a</sup>
A*B	ns	ns	ns
CV (%)	9.82	9.46	4.66

Means within the same column labeled with the same letters indicate statistically significant differences by DMRT at  $P < 0.05$ .

In LS soil, the effect of residual practices (A) showed similar effect as in SCL soil. The number of shoots in FRC at 2,4 and 6 MAH was non significantly different among the residual effect (A). For the current crop practices (B), it had no effect on number of shoots at 2 and 4 MAH but number of shoots was affected only at 6 MAH, drip fertigation treatment (S2) had the highest number of shoots (10,296 shoots/rai), while the lowest shoots number was found in rainfed condition (8,584 shoots/rai).

**Table 4.27** Effects of PC residual management and FRC management on number of shoots at 2, 4, and 6 MAH in LS soil.

Source	Number of shoots (shoots/rai)		
	2 MAH	4 MAH	6 MAH
Crop practice in PC (A)	ns	ns	ns
M1: Rainfed condition	12,593	14,716	9,629
M2: Drip irrigation + soil fertilizer	14,086	13,938	9,447
M3: Drip fertigation	14,457	12,975	9,247
Crop practice in FRC (B)	ns	ns	**
S1: Rainfed condition	14,173	13,358	8,584 <sup>b</sup>
S2: Drip fertigation	13,251	14,395	10,296 <sup>a</sup>
A*B	ns	ns	ns
CV (%)	9.82	9.46	4.66

Means within the same column labeled with the same letters indicate statistically significant differences by DMRT at  $P < 0.05$ .

## 2) Plant height.

The plant height of FRC in SCL and LS soil are shown in Tables 4.28 and 4.29, respectively.

In SCL soils, residual practice (A) did not affect plant height in FRC. while the plant height was affected by the current crop practice (B). In SCL soil, drip fertigation (S2) produced the highest plant height at 2, 4, and 6 MAH (32.3, 144, and 226 cm, respectively), while the lowest plant height at 2,4, and 6 MAH was found in rainfed conditions (21.8, 102, and 189 cm, respectively)

**Table 4.28** Effects of PC residual management and FRC management on number of shoots at 2, 4, and 6 MAH in SCL soil.

Source	Plant height (cm)		
	2 MAH	4 MAH	6 MAH
Crop practice in PC (A)	ns	ns	ns
M1: Rainfed condition	26.7	124	212
M2: Drip irrigation + soil fertilizer	26.1	125	209
M3: Drip fertigation	25.4	120	202
Crop practice in FRC (B)	**	**	**
S1: Rainfed condition	21.8 <sup>b</sup>	102 <sup>b</sup>	189 <sup>b</sup>
S2: Drip fertigation	32.3 <sup>a</sup>	144 <sup>a</sup>	226 <sup>a</sup>
A*B	ns	ns	ns
CV (%)	8.18	7.59	4.42

Means within the same column labeled with the same letters indicate statistically significant differences by DMRT at  $P < 0.05$ .

The result of plant height in LS soil is shown in table 4.29. The previous crop practice (A) affected plant height in FRC only at 4 and 6 MAH, drip fertigation produced the highest plant height at 4 and 6 MAH (77.7 and 187 cm, respectively) while rainfed residual produced the lowest plant height at 4 and 6 MAH (49.8 and 147 cm, respectively).

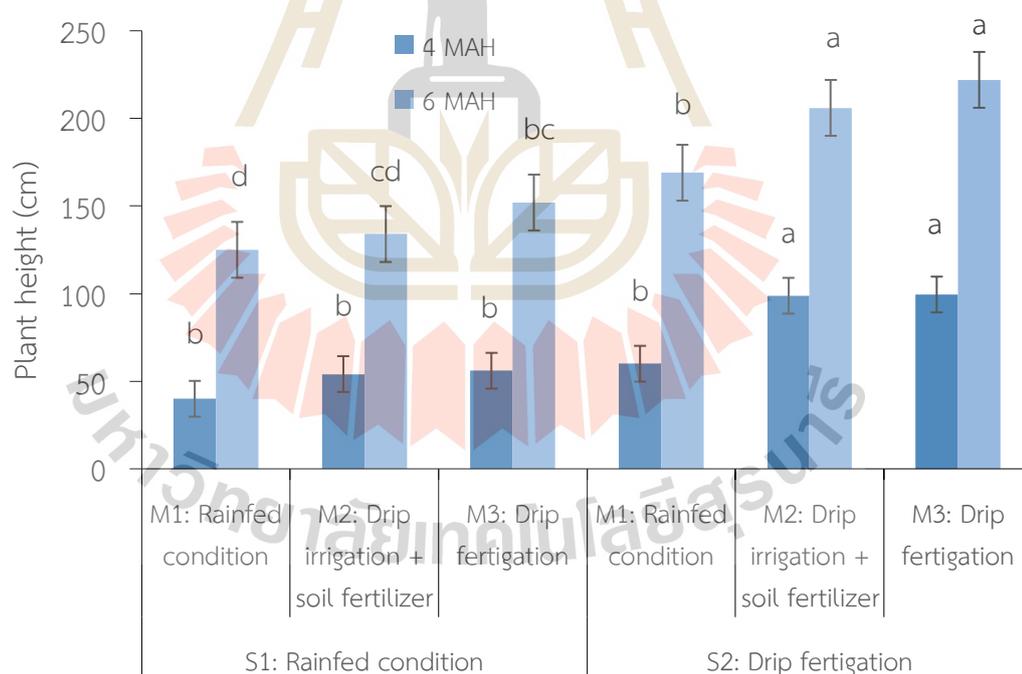
The current crop practices (B) had no effect on the plant height at 2 MAH while they affected plant height at 4 and 6 MAH i.e. drip fertigation practice (S2) in current year had higher plant height than rainfed practice (S1).

There was an interaction between the residual effect of the previous crop (A) and current crop practice (B) in LS soil at 4 and 6 MAH, the result showed that the drip fertigation practice in the current year (S2) tended to produce the higher plant height than rainfed practice in all previous year residuals (Fig 4.6).

**Table 4.29** Effects of PC residual management and FRC management on number of shoots at 2, 4, and 6 MAH in LS soil.

Source	Plant height (cm)		
	2 MAH	4 MAH	6 MAH
Crop practice in PC (A)	ns	**	*
M1: Rainfed condition	21.0	49.8 <sup>b</sup>	147 <sup>b</sup>
M2: Drip irrigation + soil fertilizer	22.0	76.5 <sup>a</sup>	170 <sup>ab</sup>
M3: Drip fertigation	27.0	77.7 <sup>a</sup>	187 <sup>a</sup>
Crop practice in FRC (B)	ns	**	**
S1: Rainfed condition	23.5	50.0 <sup>b</sup>	137 <sup>b</sup>
S2: Drip fertigation	22.7	86.0 <sup>a</sup>	199 <sup>a</sup>
A*B	ns	*	**
CV (%)	13.35	10.44	12.87

Means within the same column labeled with the same letters indicate statistically significant differences by DMRT at  $P < 0.05$ .



**Figure 4.6** Interaction effects of PC residual management and FRC management on plant height in FRC in LS soil at 4 and 6 MAH.

### 4.3.3 Yield and yield components

In SCL soil, the yield and yield components were not affected by the previous crop residuals practice (A) whereas they were affected by the current year management (B) (Table 4.30).

The current practices significantly affected yield and yield components including NMC, whereas the other traits were not affected by the current crop practice i.e. plant height, cane diameter, and TSS. The highest NMC and yield were produced in drip fertigation treatment (S2) (17,636 stalk/rai and 24.6 tons/rai), while the lowest was produced in rainfed practice (S1) (14,240 stalk/rai and 19.3 tons/rai).

**Table 4.30** Effects of PC residual management and FRC management on yield and yield components in SCL soil at 12 MAH.

Source	NMC (canes/rai)	Plant height (cm)	Cane diameter (mm)	Yield (tons/rai)	TSS (°Brix )
Crop practice in PC (A)	ns	ns	ns	ns	ns
M1: Rainfed condition	15,958	290	25.9	22.1	22.7
M2: Drip irrigation + soil fertilizer	15,741	293	25.9	21.6	22.9
M3: Drip fertigation	16,115	298	25.9	22.2	23.9
Crop practice in FRC (B)	**	ns	ns	**	ns
S1: Rainfed condition	14,240 <sup>b</sup>	292	25.4	19.3 <sup>b</sup>	22.7
S2: Drip fertigation	17,636 <sup>a</sup>	296	25.9	24.6 <sup>a</sup>	23.6
A*B	ns	ns	ns	ns	ns
CV (%)	10.30	4.94	5.40	11.60	4.25

Means within the same column labeled with the same letters indicate statistically significant differences to DMRT at  $P < 0.05$ .

In LS soil (Table 4.31), the results showed the similar effect as in SCL soil, the previous residuals (A) had no effect on yield and yield components but the current crop practices (B) were mainly factor affecting the yield and yield components in FRC. The current crop practices had significant effect on the NMC, plant height, and yield,

i.e., the highest produce was found in drip fertigation practice (S2) (17,636 cane/rai, 254 cm, and 24.6 tons/rai, respectively), while the lowest produce was found in rainfed practice (14,240 cane/rai, 206 cm, and 13.9 tons/rai, respectively).

**Table 4.31** Effects of PC residual management and FRC management on yield and yield components of FRC in LS soil at 12 MAH.

Source	NMC (canes/rai)	Plant height (cm)	Cane diameter (mm)	Yield (tons/rai)	TSS (°Brix )
Crop practice in PC (A)	ns	ns	ns	ns	ns
M1: Rainfed condition	10,744	229	29.9	13.3	22.7
M2: Drip irrigation + soil fertilizer	10,264	223	27.3	13.1	22.8
M3: Drip fertigation	10,194	240	26.3	14.0	22.5
Crop practice in FRC (B)	**	**	ns	**	ns
S1: Rainfed condition	9,302 <sup>b</sup>	206 <sup>b</sup>	27.3	11.6 <sup>b</sup>	22.6
S2: Drip fertigation	11,500 <sup>a</sup>	254 <sup>a</sup>	27.1	15.3 <sup>a</sup>	22.7
A*B	ns	ns	ns	ns	ns
CV (%)	7.64	7.81	10.33	11.42	5.83

Means within the same column labeled with the same letters indicate statistically significant differences to DMRT at  $P < 0.05$ .

#### 4.3.4 Total RLD and RLD pattern in FRC in SCL soil.

The Total RLD in FRC was affected by the residuals of previous crop, the rainfed condition residual (M1) had the highest influence on Total RLD production in FRC at 2 layers including upper and deep layers (0.863 and 0.065  $\text{cm}/\text{cm}^3$ , respectively). while drip fertigation residual (M3) had the lowest influence on Total RLD production in FRC (0.742 and 0.052  $\text{cm}/\text{cm}^3$ , respectively).

The current crop practice (B) significantly affected Total RLD production at 2 depths i.e., upper layer (0–20 cm) and deep layer (41–80). The highest TRL production was found in rainfed practice (S1) (0.842 and 0.062  $\text{cm}/\text{cm}^3$ ,

respectively) and the lowest TRL production was found in drip fertigation treatment (S2) (0.724 and 0.051 cm/cm<sup>3</sup>, respectively) (Table 4.32).

**Table 4.32** Effects of PC residual management and FRC management on Total RLD in FRC in SCL soil at 6 MAH.

Source / Depth	Total RLD (cm/cm <sup>3</sup> )		
	0–20 cm	21–40cm	41–80 cm
Crop practice in PC (A)	*	ns	*
M1: Rainfed condition	0.863 <sup>a</sup>	0.117	0.065 <sup>a</sup>
M2: Drip irrigation + soil fertilizer	0.745 <sup>b</sup>	0.141	0.051 <sup>b</sup>
M3: Drip fertigation	0.742 <sup>b</sup>	0.135	0.052 <sup>b</sup>
Crop practice in FRC (B)	**	ns	**
S1: Rainfed condition	0.842 <sup>a</sup>	0.127	0.062 <sup>a</sup>
S2: Drip fertigation	0.724 <sup>b</sup>	0.136	0.051 <sup>b</sup>
A*B	ns	ns	ns
CV (%)	12.60	9.97	16.20

Means within the same column labeled with the same letters indicate statistically significant differences by DMRT at  $P < 0.05$ .

For RLD pattern (Fig 4.7 and 4.8), In terms of the previous crop residuals (A), the rainfed residual (Fig 4.7 (M1S1) and Fig 4.8 (M1S2)) tended to produce higher RLD than the 2 irrigation residuals (M2 and M3).

In current crop practice (B), the RLD pattern of FRC was similar to the RLD pattern of PC, the rainfed practice (S1) (Fig 4.7) tended to produce the RLD in positions close to planting row and deep soil layer more than the drip fertigation treatment (S2) (Fig 4.8).

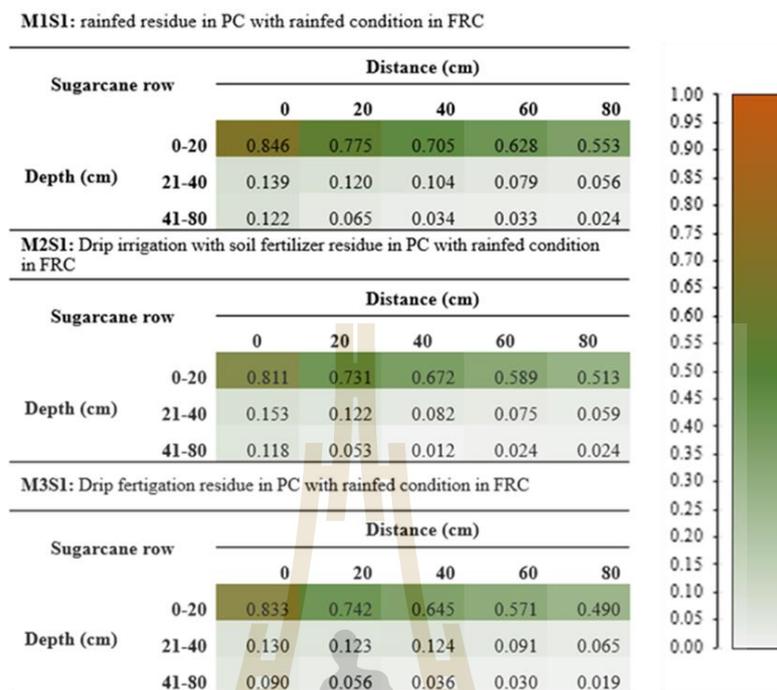


Figure 4.7 Effects of rainfed practices on RLD in FRC in SCL soil at 6 MAH ( $\text{cm}/\text{cm}^3$ ).

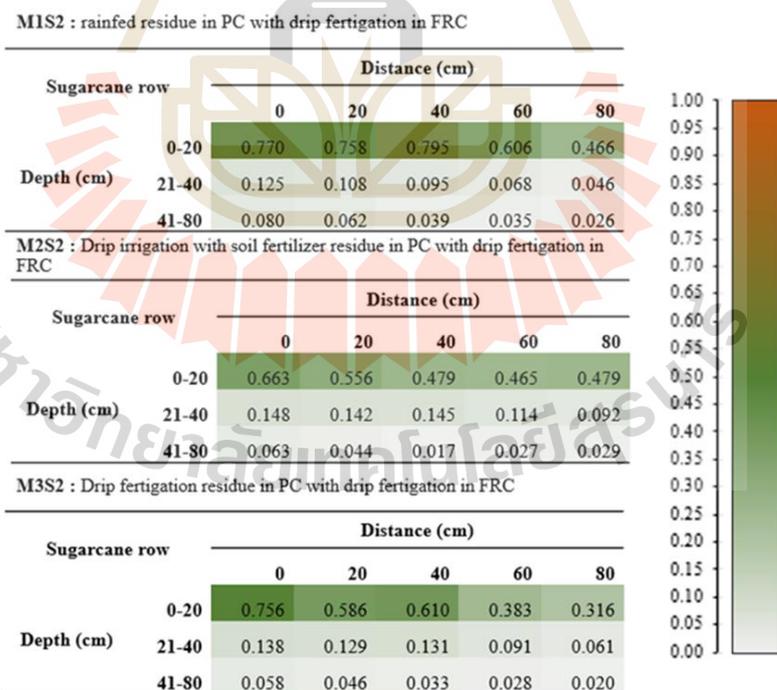


Figure 4.8 Effects of drip fertigation practices on RLD in FRC in SCL soil at 6 MAH ( $\text{cm}/\text{cm}^3$ ).

In terms of root creation (Total RLD), residual effects were the key factor to indicate the root creation in FRC. In both years, the rainfed residual which produced the highest underground structures in PC had the highest root creation in FRC. The remaining structures were positively correlated with root creation as they were the source of energy that stimulated the speed of growth and improved the vigor of the ratoon crop (Pissolato et al., 2021). The study of Aguilera Esteban et al. (2019) reported that the reduction of root trait and less crop vigor had a long-term effect on decreasing of growth in ratoon cane. In addition, the influence of rapid growth and vigor resulted from residual structures can be an indicator of the ratooning ability (RA) improvement. The study of Qin et al. (2017) demonstrated that high germination, high tillering rate, and high stalk number were found in the sugarcane cultivar with strong RA.

In terms of root distribution pattern in FRC (RLD pattern), the residual practices had little effect on root distribution. While the current year practices were the main factor to determine the root pattern in FRC. The root patterns of the rainfed condition and the drip fertigation canes were different. The rainfed condition tended to have high RLD in the surface layer and deep soil layer, while the drip fertigation tended to have high RLD only in the surface layer. The result agreed with a previous study by Chumphu et al. (2019) who reported that the distribution of roots depended on available water in the soil, in water-sufficient conditions, the root was mostly distributed in the surface layer. While Namwongsa et al. (2018) found that sugarcane when faced with drought conditions, it produced the deep root more than in normal conditions.

#### **4.3.5 Ratooning ability**

The ratooning ability (RA) in SCL and LS soil are shown in Tables 4.33 and 4.34, respectively. In SCL soil, the RA estimation based on property of growth, yield and yield component were significantly different among the residual effects of previous crop (A) and current crop practices (B).

In the residual effect of previous crop (A), rainfed residual (M1) had the highest RA which based on number of shoots at 2 MAH, number of shoots at 6 MAH, NMC at 12 MAH, and yield at 12 MAH.

In current crop practice (B), drip fertigation (S2) had higher RA which based on number of shoots at 2 MAH, number of shoots 6 MAH, NMC at 12 MAH, and yield at 12 MAH than the FRC practice with the rainfed condition (M1)

The RA based on the number of shoots at 2 MAH showed an interaction between the residual effects of previous practice (A) and the current management (B) (Fig 4.9).

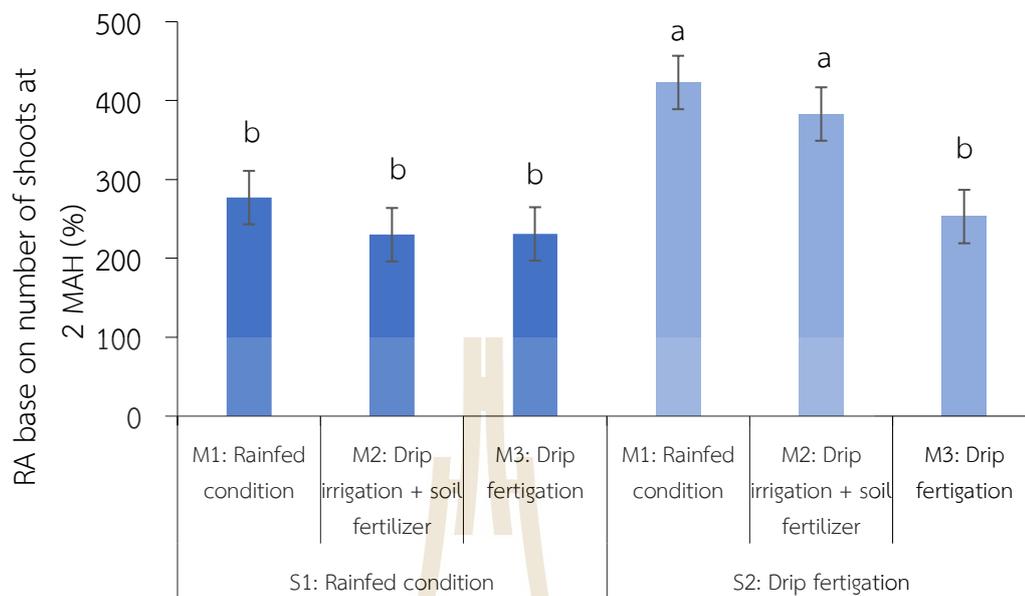
For residual effects of previous crop (A), even though RA based on number of shoots in the rainfed condition practice in FRC were not affected by the residual effects, the tendency of both FRC practices showed that rainfed residual (M1) tended to have higher RA based on number of shoots at 2 MAH than well-irrigated practice (M2 and M3).

For the current year practices (B), the result between rainfed condition (S1) and drip irrigation (S2) showed different effects on RA, all residual effects on drip fertigation in FRC practice had higher RA based on number of shoots at 2 MAH than rainfed condition.

**Table 4.33** Effects of PC residual management and FRC management on RA (%) based on number of shoots, yield and yield component in SCL soil.

Source	RA (%)			
	2 MAH		12 MAH	
	Number of shoots	Number of shoots	NMC	Yield
Crop practice in PC (A)	*	**	**	**
M1: Rainfed condition	349 <sup>a</sup>	154 <sup>a</sup>	145 <sup>a</sup>	161 <sup>a</sup>
M2: Drip irrigation + soil fertilizer	306 <sup>ab</sup>	135 <sup>b</sup>	127 <sup>a</sup>	106 <sup>b</sup>
M3: Drip fertigation	242 <sup>b</sup>	116 <sup>c</sup>	107 <sup>b</sup>	80 <sup>b</sup>
Crop practice in FRC (B)	**	*	**	**
S1: Rainfed condition	246 <sup>b</sup>	131 <sup>b</sup>	116 <sup>b</sup>	104 <sup>b</sup>
S2: Drip fertigation	352 <sup>a</sup>	140 <sup>a</sup>	137 <sup>a</sup>	128 <sup>a</sup>
A*B	**	ns	ns	ns
CV (%)	8.46	4.92	9.39	8.97

Means within the same column labeled with the same letters indicate statistically significant differences by DMRT at P < 0.05.



**Figure 4.9** The interaction effects between PC residual management and FRC management on RA (%) based on the number of shoots at 2 MAH

In LS soil, the previous crop residual effects (A) and current crop practices (B) affected RAs based on traits of growth and yield.

The previous crop practices (A) did not affect the RA based on number of shoots at 2 MAH, but significantly affected the RA based on number of shoots at 6 MAH, NMC at 12 MAH, and yield at 12 MA. The rainfed residual (M1) had a positive effect on RAs more than the 2 irrigation residuals. (M2 and M3).

In the current crop practice (B), the RA based on the number of shoots at 6 MAH, NMC at 12 MAH, and yield at 12 MAH, were the highest in drip fertigation practice (M2) (95%, 116%, and 105%, respectively.) while the rainfed practice (M1) had the lowest RAs (79%, 94%, and 79%, respectively). (Table 4.34)

**Table 4.34** Effects of PC residual management and FRC management on RA (%) based on number of shoots, yield, and yield component in LS soil.

Source	RA (%)			
	2 MAH	6 MAH	12 MAH	
	Number of shoots	Number of shoots	NMC	Yield
Crop practice in PC (A)	ns	*	*	*
M1: Rainfed condition	132	92.0 <sup>a</sup>	113 <sup>a</sup>	112 <sup>a</sup>
M2: Drip irrigation + soil fertilizer	138	86.7 <sup>b</sup>	103 <sup>b</sup>	84 <sup>b</sup>
M3: Drip fertigation	133	84.2 <sup>b</sup>	99 <sup>b</sup>	81 <sup>b</sup>
Crop practice in FRC (B)	ns	**	**	**
S1: Rainfed condition	139	79.6 <sup>b</sup>	94 <sup>b</sup>	79 <sup>b</sup>
S2: Drip fertigation	129	95.7 <sup>a</sup>	116 <sup>a</sup>	105 <sup>a</sup>
A*B	ns	ns	ns	ns
CV (%)	8.44	8.86	7.87	12.6

Means within the same column labeled with the same letters indicate statistically significant differences by DMRT at  $P < 0.05$ .

Shaw (1989) defined the RA as the performance of the ratoon crop in the percentage of growth and yield in ratoon cane compared to PC. The good RA cane has long ratoon keeping and low yield decrease in the next ratoon crop. In contrast, poor RA was defined when the performance of the ratoon was lower than PC (Qin et al., 2017).

The result of this experiment showed that previous crop practice and current crop practice influenced the RA in FRC. For previous crop practice, a rainfed condition which produced high underground structures (root and underground stubble) had the highest RA in FRC. High underground structure accumulation was positively related to high initial growth of FRC. The result agreed with other previous studies such as Kumar et al. (2017) and Xu et al. (2021) who reviewed that the residual crop practice which produced a strong root system and high underground structure influenced high RA since it was related to improving next ratoon germination and growth. The rapid growth in the initial stage of the ratoon crop was an early indicator of high RA. A similar study by Qin et al. (2014) and Milligan et al. (1990) found that sugarcane cultivars with strong RA had fast germination,

high tillering, and high shoot production. A study of Hogarth and Berding (2006) found that low germination rates had a long-term effect on reducing effective tillers and millable shoots, which was positively correlated to the reduction in RA.

In terms of RA improvement, although the residual effect was the factor that improved the speed of the initial growth of the ratoon crop, but the current year's practice was more important for improving the growth of the current crop. For current crop practices, the drip fertigation which produced the highest number of shoots, the best growth, and the highest effective shoot in the current year had higher RA than those performed in rainfed conditions. A similar result was obtained by Uribe et al. (2013) found that the ratoon cane practice with drip fertigation tended to have better growth than no irrigation. Bashir et al. (2013) also found that good growth in the ratoon crop (the high shoots population, high millable shoot, and high yield) was essential for the indication of the strong RA. This result was supported by Gomathi et al. (2013) who found that the RA positively affected the ratoon germination, thereby directly increased the shoot population and ratoon yield.

Even though drip fertigation produced the highest growth, yield, and RA, but it tended to have lower underground structures creation (root and stubble) than the rainfed condition which had a negative effect on the growth and vigor of the next ratoon crop when it was grown under non-suitable conditions (rainfed conditions). Therefore, the effective practice such as drip fertigation in the PC should be continued in the ratoon crops to keep high RA in all canes. Wonprasaid and Girdthai (2014) also found that in 3 continually years of practice between rainfed conditions and drip irrigation, drip irrigation practice was able to maintain higher RA based on the yield of first and second ratoon cane (91.0 and 101%, respectively) than the rainfed condition (89.3% and 73.3%, respectively). However, although this study showed that rainfed conditions had high RA, if the sugarcane was managed with improper methods for a long time or faced long-term drought stress, it could decline the RA since the vigor of sugarcane under rainfed conditions declined following age (Bhale 1943). Luanmanee et al. (2021) also found that the long-term practice with the rainfed conditions could reduce RA of FRC and SRC to 51.7 and 36.5%, which RA decline was not worth for further ratoon keeping.

**Table 4.35** Correlations value among the treatments of PC on phenotypic traits yield and yield components in PC.

Correlations	Underground stubble			No. of shoots			Yield	NMC	
	(DW)	RLDU	RLDM	RLDD	2 MAP	4 MAP			6 MAP
Underground stubble (DW)	1	0.666**	0.529*	0.662**	-0.307	-.757*	-0.407	-0.499	
RLDU		1	.796*	.999**	-0.497	-.869**	-0.524	-.692*	
RLDM			1	.827**	-.851**	-.947**	-.911**	-.958**	
RLDD				1	-.537	-.890**	-0.568	-.727*	
No. of shoots 2 MAP					1	.728*	.962**	.873**	
No. of shoots 4 MAP						1	.813**	.872**	
No. of shoots 6 MAP							1	.907**	
Yield								1	
NMC									1

\*\*\*, Correlation is significant at the 0.01 and 0.05 level (2-tailed), respectively.

**Table 4.36** Correlations value among the old residual structures of PC on phenotypic traits and RAs of FRC.

Correlations	Underground stubble (PC)	RLDU (PC)	RLDM (PC)	RLDD (PC)	Germination (%)	No. of shoots 2 MAH	NMC (FRC)	Yield (FRC)	RA(%) NMC	RA(%) yield
Underground stubble (PC)	1	.666**	.529*	.662**	0.320	0.159	0.146	0.191	0.435	.613**
RLDU (PC)		1	.773**	.990**	0.446	0.202	0.041	0.045	.495*	.762**
RLDM (PC)			1	.856**	.639**	0.295	0.018	0.009	.725**	.896**
RLDD (PC)				1	.508*	0.232	0.038	0.039	.567*	.824**
Germination (%)					1	.699**	0.257	0.314	.579*	.689**
No. of shoots 2 MAH						1	.665**	.698*	.598**	.539*
NMC (FRC)							1	.888*	.660**	0.362
Yield (FRC)								1	.565*	0.431
RA(%) NMC									1	.854**
RA(%) yield										1

\*, \*\* Correlation is significant at the 0.01 and 0.05 level (2-tailed), respectively.

## CHAPTER V

### CONCLUSION

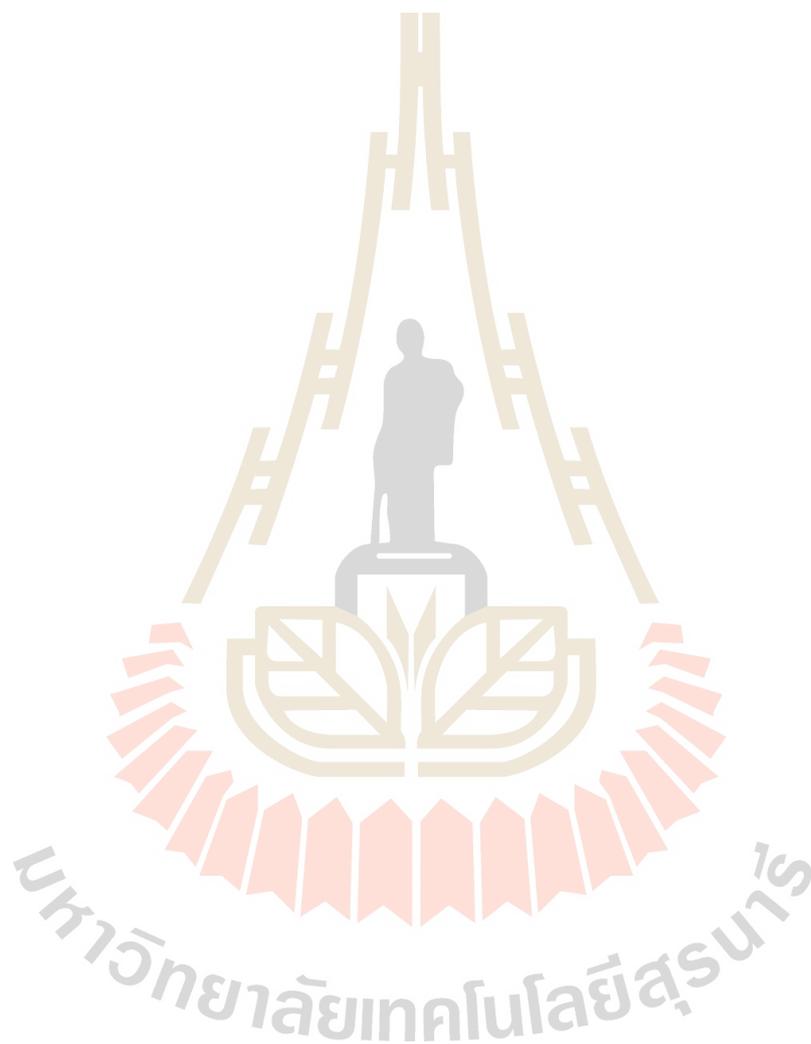
A series of 2 years experiments were conducted in 2 different soils (Sandy clay loam soil, and Loamy sand soil) to determine water and fertilizer management on yield and ratooning ability (RA) of sugarcane. It was found that 2 soil textures had similar results in both years. Drip irrigation practices had better growth performances and also produced higher yield and yield components than the rainfed conditions. The drip irrigation practice had a higher average yield than rainfed conditions by 34–58% in plant cane (PC) and 32–37% in 1<sup>st</sup> ratoon cane (FRC).

In the comparison of fertilizer applications (soil fertilizer application and fertigation), the results showed that fertigation had better growth and yield production than the soil fertilizer application. The number of millable cane (NMC) was 16.4 % and the yield was 22.4% higher under fertigation than under the soil fertilizer application. Additionally, under the same rate of fertilizer and water supply, drip fertigation which produced a higher yield also had higher Irrigation water use efficiency and fertilizer nutrient use efficiency than soil fertilizer application by 15% and 23% respectively.

For RA evaluation, the results showed that both year practices (PC and FRC) influenced the RA of FRC sugarcane. For the previous crop effects (PC residual), the rainfed residual which produced high underground structures (root and stubble) had the highest initial ratoon germination, RA based on NMC, and RA based on yield. For the current crop practice (Current year practice in FRC), drip fertigation practice had higher RA based on NMC, and yield than rainfed conditions.

The NMC and yield of the FRC did not depend on initial RAs. RA was only an indicator of the adaptability and high vigor of ratoon seedlings but the NMC and yield of FRC were much more associated with the current crop management. Regardless of all residual practices, the current crop fertigation practice produced a higher yield than the rainfed condition practices. Even though drip fertigation was the most effective way to produce growth and yield, but with low RA, it reduced the vigor and adaptability in the next ratoon cane if grown under non suitable condition, including,

under rainfed condition. Therefore, drip irrigated sugarcane must be grown under the same practices for all ratoons to maintain growth, yield and RA.



## REFERENCES

- Agresti, A. (2015). *Foundations of linear and generalized linear models*. Wiley.
- Anderson, D. L., & J. E. Bowen. (1990). *Sugarcane nutrition*. Atlanta, GA: Potash and Phosphate Institute.
- Basu, S., Ramegowda, V., Kumar, A., & Pereira, A. (2016). Plant adaptation to drought stress. *F1000Research*, 5, 1554.
- Begum, K., Sikder, A. H. F., Khanom, S., Hossain, M. F., & Parveen, Z. (2016). Nutrient uptake by plants from different land types of Madhupur soils. *Bangladesh Journal of Scientific Research*, 28(2), 113–121.
- Begum, M. K., Alam, M. R., Islam, M. S., & Arefin, M. S. (2012, February 11). Effect of Water stress on physiological characters and juice quality of sugarcane. *An International Journal of Sugar Crops and Related Industries*, 14(2), 161–167.
- Berding, N., & Hurney, A. P. (2005). Flowering and lodging, physiological-based traits affecting cane and sugar yield. *Field Crops Research*, 92(2–3), 261–275.
- Bhale, V. M. G. (1943). Effect of growth regulators and cultural treatment on productivity of ratoon cane. *Indian Sugar*, 44(8), 645–651.
- Blake, G.R. & Hartge, K.H. (1986). *Bulk density*. In: Klute, A., Ed., *Methods of soil analysis, part 1 physical and mineralogical methods*, 2nd Edition, Agronomy Monograph 9, American Society of Agronomy-Soil Science Society of America, Madison, 363-382.
- Blum, A. (2005). Drought resistance, water-use efficiency, and yield potential are they compatible, dissonant, or mutually exclusive?. *Australian Journal of Agricultural Research*, 56(11), 1159.
- Bouyoucos, G. J. (1962). Hydrometer method improved for making particle size analyses of soils 1. *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.

- 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.
- Chadha, A., Florentine, S. K., Chauhan, B. S., Long, B., & Jayasundera, M. (2019). Influence of soil moisture regimes on growth, photosynthetic capacity, leaf biochemistry and reproductive capabilities of the invasive agronomic weed; *Lactuca serriola*. *a peer-reviewed open access scientific journal*, 14(6), e0218191.
- Chumphu, S., Jongrunklang, N., & Songsri, P. (2019). Association of physiological responses and root distribution patterns of ratooning ability and yield of the second Ratoon cane in sugarcane elite clones. *Agronomy*, 9(4), 200.
- David, D. J. (1960). The application of atomic absorption to chemical analysis. A review. *The Analyst*, 85(1016), 779.
- Eswaran, S. (Ed.). (2017). *DRIP IRRIGATION-full paper*.
- FAO. (unpublished). *CHAPTER 3: Crop water needs* [Dataset]. <https://www.fao.org/3/S2022E/s2022e07.htm#TopOfPage>
- Faye, A., Sine, B., Chopart, J. L., Grondin, A., Lucas, M., Diedhiou, A. G., Gantet, P., Cournac, L., Min, D., Audebert, A., Kane, A., & Laplaze, L. (2019). Development of a model estimating root length density from root impacts on a soil profile in pearl millet (*Pennisetum glaucum* (L.) R. Br). Application to measure root system response to water stress in field conditions. *Peer-reviewed open access scientific journal*, 14(7)
- Ferraris, R. & Chapman, L.S. (1991). *Effect of moisture regime on early development of ratoon buds*. Proceedings of Australian Society Sugar Technology, 172–178.
- Figuroa-Rodríguez, K. A., Hernández-Rosas, F., Figuroa-Sandoval, B., Velasco Velasco, J., & Aguilar Rivera, N. (2019). What has been the focus of sugarcane research? A bibliometric overview. *International Journal of Environmental Research and Public Health*, 16(18), 3326.
- Gentile, A., Dias, L. I., Mattos, R. S., Ferreira, T. H., & Menossi, M. (2015). MicroRNAs and drought responses in sugarcane. *Frontiers in Plant Science*, 6.
- Gomathi, R., Rao, P. N. G., Rakkiyappan, P., Sundara, B. P., & Shiyamala, S. (2013). Physiological studies on ratoonability of sugarcane varieties under tropical Indian condition. *American Journal of Plant Sciences*, 04(02), 274–281.

- Hassan, M. U., Fiaz, N., Mudassir, M. A., & Yasin, M. (2017). Exploring the ratooning potential of sugarcane (*Saccharum officinarum* L.) genotypes under varying harvesting times of plant crop. *Pakistan Journal of Agricultural Research*, 30(3).
- Hatfield, J. L., & Dold, C. (2019). Water-use efficiency: Advances and challenges in a changing climate. *Frontiers in Plant Science*, 10.
- 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)*, 6(1), 91-95.
- Hogarth, D. M., & Berding, N. B. (2006). Breeding for a better industry: Conventional breeding sugarcane international. *Sugarcane International*, 24(2), 26–31.
- Htoon, W., Kaewpradit, W., Vorasoot, N., Toomsan, B., Akkasaeng, C., Puppala, N., Wongkaew, S., & Jogloy, S. (2019). Relationships between nutrient uptake and nitrogen fixation with aflatoxin contamination in peanut under terminal drought. *Agronomy*, 9(8), 419.
- Jangpromma, N., Songsri, P., Thammasiri, S., & Jaisil, P. (2010). Rapid assessment of chlorophyll content in sugarcane using a SPAD chlorophyll meter across different water stress conditions. *Asian Journal of Plant Sciences*, 9(6), 368-374.
- Jangpromma, N., Thammasirirak, S., Jaisil, P., & Songsri, P. (2012). Effects of drought and recovery from drought stress on above ground and root growth, and water use efficiency in sugarcane (*Saccharum officinarum* L.). *Australian Journal of Crop Science*, 6(8), 1298-1304.
- Johnston, A., & Bruulsema, T. (2014). 4R Nutrient stewardship for improved nutrient use efficiency. *Procedia Engineering*, 83, 365-370.
- Kafkafi, U. and Tarchitzky, J. (2011) *Fertigation: A tool for efficient fertilizer and water management*. International Fertilizer Industry Association, Paris.
- Kawakami, J., Iwama, K., & Jitsuyama, Y. (2006). Soil water stress and the growth and yield of potato plants grown from microtubers and conventional seed tubers. *Field Crops Research*, 95(1), 89-96.

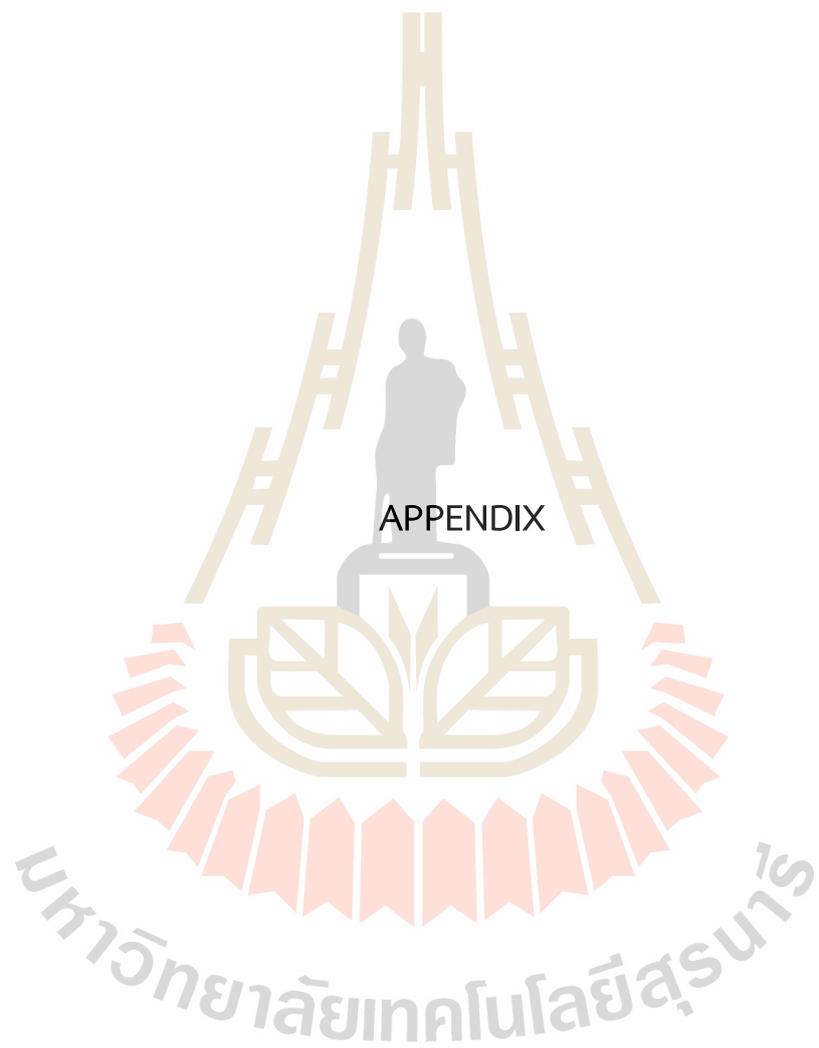
- Khonghintaisong, J., Songsri, P., Toomsan, B., & Jongrunklang, N. (2017). Rooting and physiological trait responses to early drought stress of sugarcane cultivars. *An International Journal of Sugar Crops and Related Industries*, 20(4), 396-406.
- Kolange, A.K., Pilane, M.S., Munde, M.S., and Bhoi, P.G. (2001). Effect of fertilizer levels on yield and quality of new sugar-cane genotype. *Indian Sugar*, 50(11): 375-378.
- Kombali, G., Sheshadri, T., Thimmegowda, M., & Basavaraja, P. (2016). Performance of sugarcane under varied levels of irrigation and nutrients through subsurface drip fertigation. *Mysore Journal of Agricultural Sciences*, 50(2), 290-293.
- Kooyers, N. J. (2015). The evolution of drought escape and avoidance in natural herbaceous populations. *Plant Science*, 234, 155-162.
- Kumar, S., Singh, S., Yadav, S. P., Srivastav, M., Singh, I., & Sharma, B. (2017). Effect of cultural operations and fertilizer application in ratoon for enhancing the sugarcane ratoon cane productivity. *Agrica*, 6(1), 62.
- Luanmanee, S., Kongtien, D., Chongchuaklang, K., & Wandee, W. (2021). Effect of supplemental water and fertilizer rates on yield of three sugarcane cultivars grown on clay soil at Nakhon Sawan province. *Thai Agricultural Research Journal*, 39(3), 232-247.
- McCray, J. M., Ezenwa, I. V., Ronald, W. R., & Timothy, A. L. (unpublished). *Sugarcane plant nutrient diagnosis* [Dataset]  
[http://www.nutricaoeplantas.agr.br/site/downloads/unesp\\_jaboticabal/omissao\\_cana4.pdf](http://www.nutricaoeplantas.agr.br/site/downloads/unesp_jaboticabal/omissao_cana4.pdf)
- Milligan, S. B., Gravois, K. A., Bischoff, K. P., & Martin, F. A. (1990). Crop effects on broad-sense heritabilities and genetic variances of sugarcane yield components. *Crop Science*, 30(2), 344.
- Namwongsa, J., Jongrunklang, N., & Songsri, P. (2018). *Genotypic variation in root distribution changes and physiological responses of sugarcane induced by drought stress* [Unpublished manuscript].
- Niaz, S., Ali, M. A., Ali, S., & Awan, S. (2009). Comparative water use efficiency of drip and furrow irrigation systems for off-season vegetables under plastic tunnel in rainfed areas. *Life Sciences International Journal*, 2, 952-955.

- Office of Cane and Sugar Board. (2019). *Report of sugarcane planting situation of the production year 2019/2020*. Information and Communication Technology Group.
- Office of the Cane and Sugar Board. (2018). *Report on sugarcane production in Thailand for the production year 2017/18*. Information and Communication Technology Group.
- Olaoye, G. (2008). Estimate of ratooning ability in sugarcane (*Saccharum officinarum* L) under conditions of low-available soil moisture in a savanna ecology of Nigeria. *Moor Journal of Agricultural Research*, 6(1).
- Onwueme, C., & Sinha, T. D. (1999). *CTA-Field crop production in tropical Africa*. Wageningen, Netherlands.
- Pawar, D., Sachin, D., & Surve, U. s. (2013). Growth, yield, and water use in sugarcane (*Saccharum officinarum*) under drip fertigation. *Indian Journal of Agronomy*, 58(2), 16-21.
- Pereira, L., Paredes, P., & Jovanovic, N. (2020). Soil water balance models for determining crop water and irrigation requirements and irrigation scheduling focusing on the FAO56 method and the dual Kc approach. *Agricultural Water Management*, 241.
- Pierre, J. S., Rae, A. L., & Bonnett, G. D. (2014). Abiotic limits for germination of sugarcane seed in relation to environmental spread. *Tropical Plant Biology*, 7(3-4), 100-110.
- Pissolato, M. D., Cruz, L. P. D., Silveira, N. M., Machado, E. C., & Ribeiro, R. V. (2021). Sugarcane regrowth is dependent on root system size: an approach using young plants grown in nutrient solution. *Bragantia*, 80.
- Qin, W., CaiWen, W., Jun, Z., PeiFang, Z., Kun, Y., XueKuan, C., Li, Y., & QianChun, Z. (2017). Research on ratoon ability of sugarcane: I. Relationship between ratooning ability and morphological characteristics of ratoon stools. *Southwest China Journal of Agricultural Sciences*, 30(5), 989-993.
- Qin W., Wu C.W., Yao L., Chen X.K., Zhao P.F., Zeng Q.Q. (2014). Relationship between ratoon ability and the change of endogenous hormone in sugarcane at sprouting stage. *Acta Botanica Boreali-Occidentalia Sinica.*, 34(1), 143-149

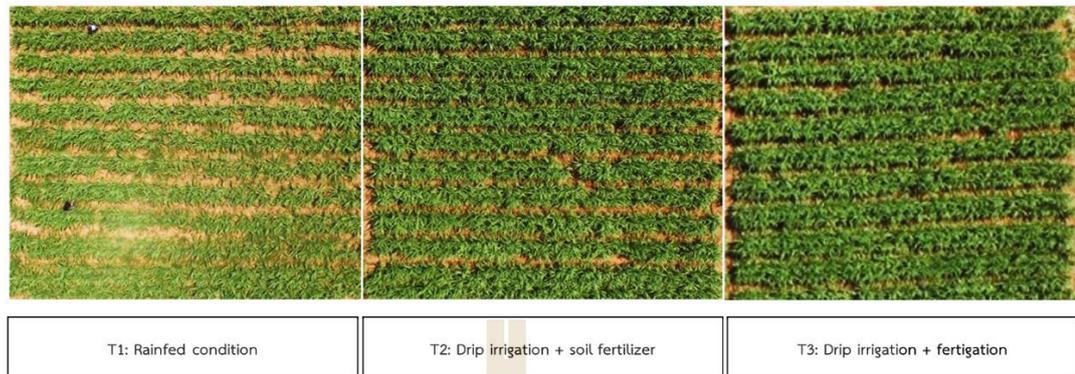
- Quaggio, J. A., Mattos, D., & Cantarella, H. (2006). Fruit yield and quality of sweet oranges affected by nitrogen, phosphorus and potassium fertilization in tropical soils. *Fruits*, 61(5), 293-302.
- Radhamani, R., Kannan, R., & Rakkiyappan, P. (2015). Leaf chlorophyll meter readings as an indicator for sugarcane yield under iron deficient typical haplustert. *An International Journal of Sugar Crops and Related Industries*, 18(1), 61-66.
- Richardson, A. D., Duigan, S. P., & Berlyn, G. P. (2002). An evaluation of noninvasive methods to estimate foliar chlorophyll content. *New Phytologist*, 153(1), 185-194.
- Royal Irrigation Department. (unpublished). *Crop Coefficient; Kc* [Dataset]. [http://water.rid.go.th/hwm/cropwater/CWRdata/Kc/kc\\_th.pdf](http://water.rid.go.th/hwm/cropwater/CWRdata/Kc/kc_th.pdf)
- Sangnark, A., & Noomhorm, A. (2004). Effect of dietary fiber from sugarcane bagasse and sucrose ester on dough and bread properties. *LWT - Food Science and Technology*, 37(7), 697-704.
- Sathiyaraj, M., & priya, S. (2017). Irrigation regimes and fertigation levels on sugarcane under subsurface drip fertigation. *International Journal of Current Microbiology and Applied Sciences*, 6(11), 3674-3684.
- Sehtiya H.L., Dendsay J.P.S. (1992). Sugarcane ratooning ability I. study on morphology of stubbles. *Indian Sugar*, 42, 751-754.
- Shaw M.E.A. (1989). An index to measure sugar cane ratoon performance. *Sugar Azucar*. 84, 22-23.
- Shrivastava, A., Srivastava, T., Srivastava, K., Varucha, M., Srivastava, S., & Vinay, S. (2016). *Climate change induced abiotic stresses affecting sugarcane and their mitigation* (1st ed.). ICAR-IISR, Lucknow.
- Shedeed, S., Zaghoul, S., & Yassen, A. azim. (2009). Effect of method and rate of fertilizer application under drip irrigation on yield and nutrient uptake by tomato. *Ozean journal of applied sciences*, 2.
- Singh, P., Rai, R. K., Suman, A., Srivastava, T. K., Singh, K. P., Arya, N., & Yadav, R. L. (2014). Soil-root interface changes in sugarcane plant and ratoon crops under subtropical conditions: Implications for dry-matter accumulation. *Communications in Soil Science and Plant Analysis*, 46(4), 454-475.

- Sinworn, S. (2014). *Effect of Drip irrigation systems fertigation and soil fertilization on growth and yield of Cassava*. [MS Thesis, Kasetsart University], Bangkok.
- Smith DM, Inman-Bamber NG, Thorburn PJ (2005) Growth and function of the sugarcane root system. *Field Crop Research*, 92, 169-183.
- Songsri P., Jogloy S., Holbrook CC, Kesmala T., Vorasoot N., Akkasaeng C., & Patanothai A. (2009) Association of root, specific leaf area and SPAD chlorophyll meter reading to water use efficiency of peanut under different available soil water. *Agricultural water management*, 96, 790-798.
- The American River Water Education Center. (unpublished). *Water facts - Worldwide water supply* [Dataset]. <https://www.usbr.gov/mp/arwec/water-facts-wwwater-sup.html>
- Thongaram, D., Tangkosakul, W., Jiracheewee, N., and Nuntagij, I. (2002). *Design and technology of irrigation for plant*. Mitkaset Marketing and Advertising Press, Bangkok, Thailand.
- Thong-ob, T. (2013). *Effects of soil moisture content on root distribution and physiological traits of cassava*. [Master's Thesis, Suranaree University of Technology], Nakhon Ratchasima. <http://sutir.sut.ac.th:8080/jspui/handle/123456789/8747>
- Tippayawat, A., Ponragdee, W., & Sansayawichai, T. (2012). Characteristics of Thai sugarcane (*Saccharum* spp. hybrids) cultivars and potential for utilization. *Khon Kaen Agriculture Journal (Thailand)*, 53-59.
- Trimble, S. (2022, September 21). *The importance of leaf area index (LAI) in environmental and crop research*. CID Bio-Science. <https://cidinc.com/blog/the-importance-of-leaf-area-index-in-environmental-and-crop-research>
- United States Department of Agriculture. (2022). *Sugar: World markets and trade*. <https://apps.fas.usda.gov/psdonline/circulars/sugar.pdf>
- Uribe, R. A. M., Gava, G. J. D. C., Saad, J. C. C., & Kölln, O. T. (2013). Ratoon sugarcane yield integrated drip-irrigation and nitrogen fertilization. *Engenharia Agrícola*, 33(6), 1124-1133.
- 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, 251-264.

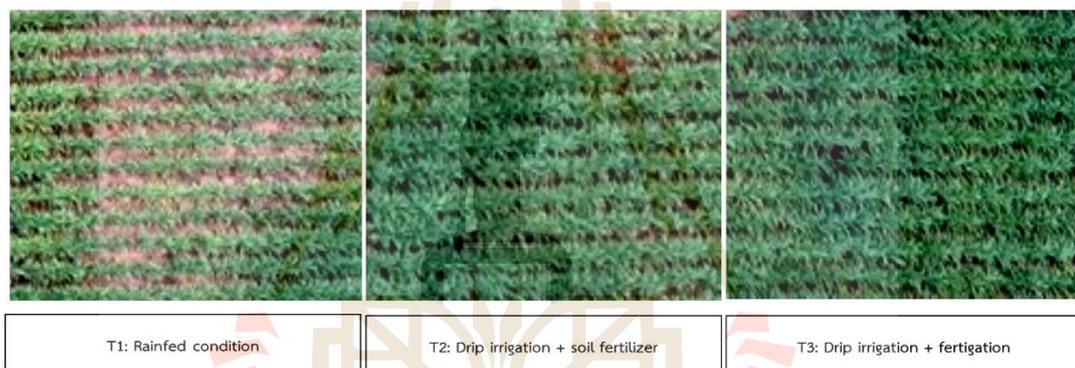
- Wasaya, A., Zhang, X., Fang, Q., & Yan, Z. (2018). Root phenotyping for drought tolerance: A review. *Agronomy*, 8(11), 241.
- Wiangnon, C., Puangbut, D., Jongrunklang, N., & Songsri, P. (2021). Root traits and root distribution patterns in advance sugarcane clones under early drought stress conditions. *Khon Kaen Agriculture Journal (Thailand)*, 3(49), 609–621.
- Wiedenfeld, B., & Enciso, J. (2008). Sugarcane responses to irrigation and nitrogen in semiarid south Texas. *Agronomy Journal*, 100(3), 665-671.
- Wonprasaid, S., & Girdthai, T. (2014). *Management for ratoon yield improvement of sugarcane in the northeast*. Institute of Agricultural Technology, School of Crop Production Technology, Suranaree University of Technology.
- Xie, X. (2018). *Fertigation for cassava production under drip irrigation system*. [Doctoral dissertation, Suranaree University of Technology], Nakhon Ratchasima <http://sutir.sut.ac.th:8080/jspui/handle/123456789/8426>
- Xu, F., Wang, Z., Lu, G., Zeng, R., & Que, Y. (2021). Sugarcane ratooning ability: Research status, Shortcomings, and Prospects. *Biology*, 10(10), 1052.
- Yadav, R.L., Kumar, R., & Verma, R.S. (1991). Effect of planting technique and planting density on yield of late planted sugarcane in north central India. *Experimental agriculture*, 27(3), 281-286.
- Yadav, R. L., & Prasad, S. R. (1988). Moisture use characteristics of sugarcane genotypes under different available soil moisture regimes in alluvial entisols. *The Journal of Agricultural Science*, 110(1), 5-11.
- Zotarelli, L., Scholberg, J. M., Dukes, M. D., & Muñoz-Carpena, R. (2008). Fertilizer residence time affects nitrogen uptake efficiency and growth of sweet corn. *Journal of Environmental Quality*, 37(3), 1271-1278.



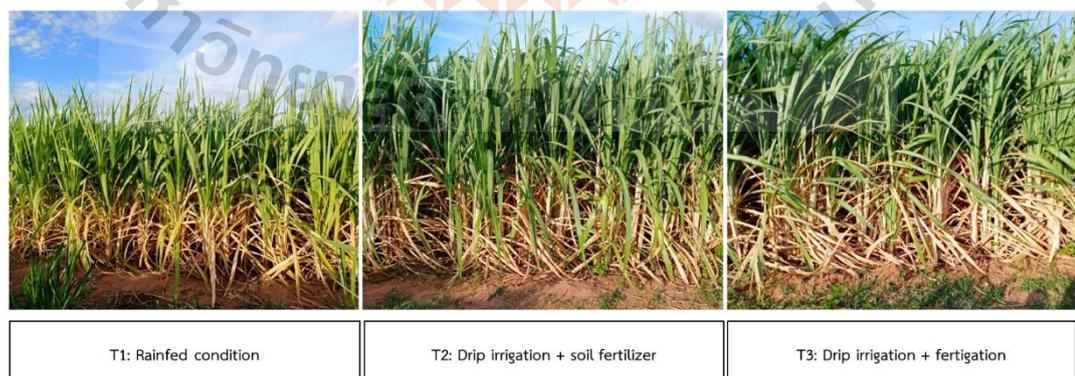
APPENDIX



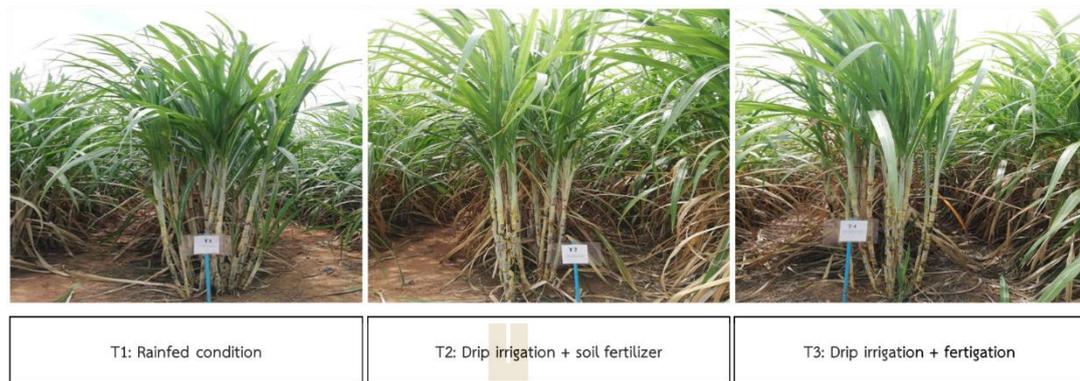
**Attached Figure 1** Effects of drip irrigation and fertigation treatments in plant cane (PC) in sandy clay loam soil (SCL) at 2 month after planting (MAP)



**Attached Figure 2** Effects of drip irrigation and fertigation treatments in PC in loamy sand soil (LS) at 2 MAP



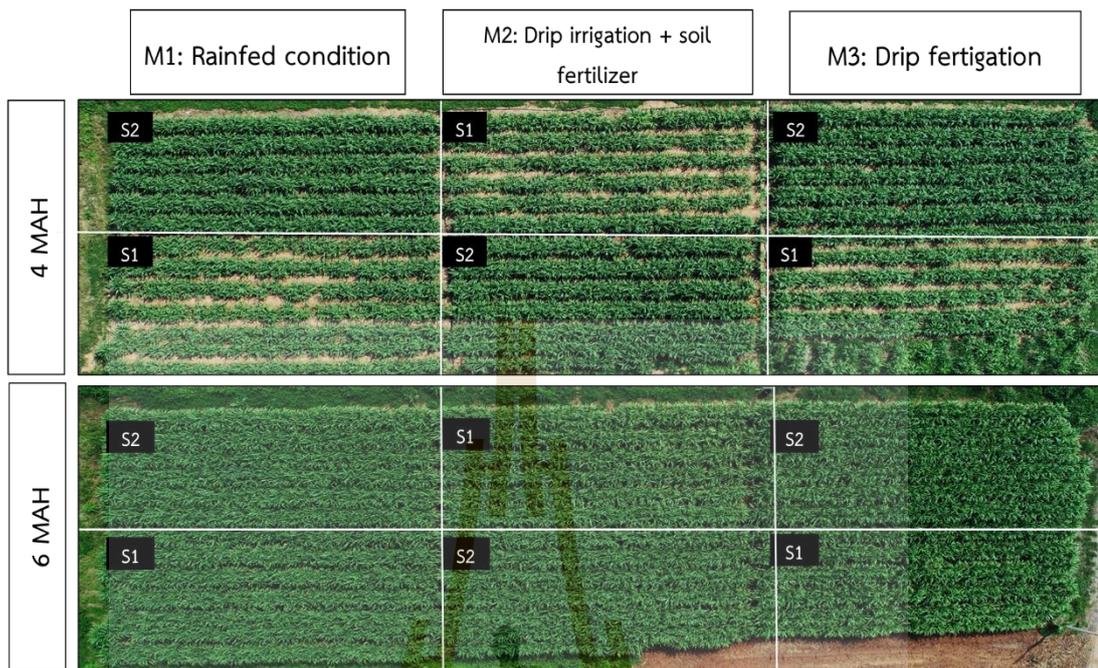
**Attached Figure 3** Effects of drip irrigation and fertigation treatments in PC in SCL at 8 MAP



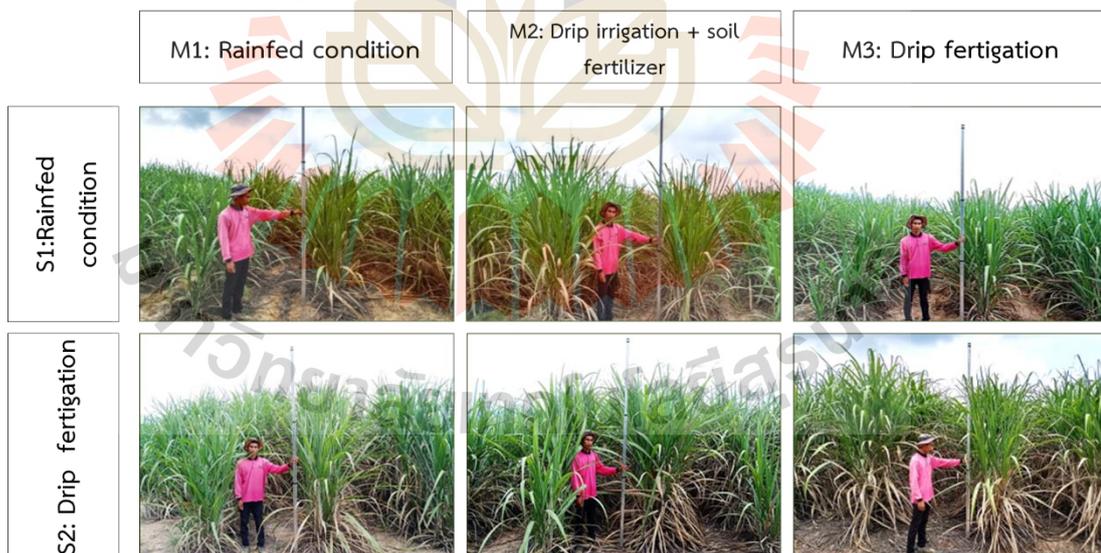
Attached Figure 4 Effects of drip irrigation and fertigation treatments in PC in LS at 8 MAP



Attached Figure 5 Effects of the previous year and current year management in first ratoon cane (FRC) in SCL at 2 month after harvest (MAH)



Attached Figure 6 Effects of the previous year and current year managements in FRC in SCL at 4 and 6 MAH



Attached Figure 7 Effects of the previous year and current year managements in FRC in LS at 4 MAH

## BIOGRAPHY

Mr. Yuphadet Tesmee, he graduated the primary 1-6 and secondary 1-6 from Saint's Mary collage high school, Nakhon Ratchasima, Thailand. In 2014, he studied bachelor's degree in School of Crop production Technology, Suranaree University of Technology and graduated with the first-class honor in 2017

After graduated the bachelor's degree, he continued to study in degree of master science program in 2018 in School of Crop Production Technology, Institute of Agricultural Technology, Suranaree University of Technology. Nakhon Ratchasima, Thailand.

