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 1st 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 incase 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 ca=e 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).

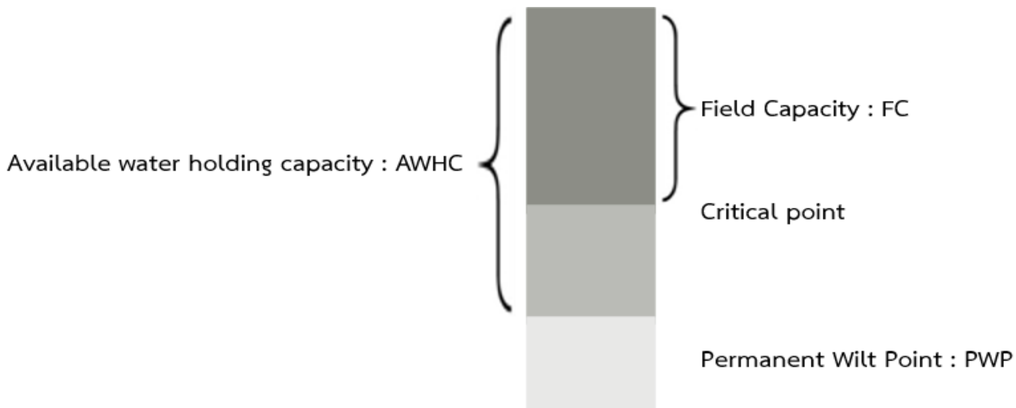

Figure 2.1 The relationship between soil moisture and the determination of the water of plants.

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	ETc	=	Crop Evapotranspiration
	Kp	=	Class A Pan coefficient
	Epan	=	Class A Pan Evapotranspiration
	Kc	=	Crop coefficient

iii) Class A Pan Evapotranspiration (Epan) and Class A Pan coefficient (K'p) The ETc equation is shown as follows

$$ETc = K'p \times Epan \times Kc$$

Where	ETc	=	Crop Evapotranspiration
	K'p	=	Class A Pan coefficient
	Epan	=	Class A Pan Evapotranspiration
	Kc	=	Crop coefficient

ETc calculated from climate data using ETp and Kc is the most popular method because it can obtain results easily without installing equipment or measuring Epan, but it needs ETp of planting area and Kc 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 (Kc) value of sugarcane.

Months	Crop coefficient (Kc)						
	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 (ETp) 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^3)		Yield (kg/acre)		WUE (kg/m^3)	
	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, FNUE of fertigation had higher by 80 to 90 percent than soil application which had a lower FNUE 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 influent the ratooning ability of sugarcane.