CHAPTER II
LITERATURE REVIEW

2.1 The importance of sugarcane and sugarcane production situation

Sugarcane (*Saccharum officinarum* L.) is in a family of Gramineae, the same family as bamboo, grass and grains such as wheat, rice, corn and barley. Zhang et al. (2019) has divided the plants of this genus into 6 species i.e., S. *spontaneum*, S. *robustum*, S. *officinarum*, S. *barberi*, S. *sinense* and S. *edule*.

Currently, Thailand is the second largest exporter of sugar in the world after Brazil. The world's major sugar consumers are India and China. Although Brazil is the largest sugar exporter in the world, delivering sugar to big market (Asian countries) results in high shipping costs that gives Thailand an advantage in terms of transportation costs. High sugar production is also an advantage point that Thai sugar can compete with Brazil.

The Brazilian Ministry of Trade reported that Brazil exported 1.21 million tons of sugar in February 2019 (raw sugar value) increased 10 percent from 1.10 million tons in January 2019 but that decreased 17.69 percent from 1.47 million tons in the same period last year. The Indian Sugar Association reported that in the production season 2018/19, sugar factories have 2.20 million tons of sugar contracts starting on October in 2018. The sugar factories have already delivered more than 1 million tons of white sugar and almost equal raw sugar to Bangladesh, Sri Lanka and Somalia. The Production Management Center, Office of Cane and Sugar Board reported that sugarcane from November 20, 2018 to March 15, 2019 there were 112,570,547 tons of sugarcane harvested into the sugar mill where it produced 9,722,334 tons of raw sugar and 2,530,153 tons of white sugar. The sweetness of sugarcane is 12.47 CCS. Average sugar yield per ton of sugarcane is 108.84 kg per ton (Office of Agricultural Economics, 2019). The major production sites are in the northeast, Nakhon Ratchasima, Udon Thani and Khon Kaen (Office of the Cane and Sugar Board, 2017) In the production year 2016/17, there were 47 provinces of sugarcane cultivation in the survey area of Thailand, with total growing area of 10,988,489 rai.

2.2 Growth of sugarcane

The growth of sugarcane is divided into 4 phases.

2.2.1 Germination phase

It starts from planting until shoots emerge in the soil that will take about 2– 3 weeks, which depends on many factors such as varieties, soil types and environmental conditions. The number of seedlings per rai will determine the production of sugarcane per unit area.

2.2.2 Tillering phase

Tillering will start from 1.5 to 2.5–4 months after planting (MAP). Clumping is a physiological process of repetition under the ground. The factors that affect the tillering number include soil moisture, light, temperature, and fertilizer. When shoots occur in the beginning, they will be strong, but if shoots occur in the end, there will be a chance to die or not fully grow. Controlling water and weeds are very important during the tillering period, and also important for cracking, which can stimulate the number of shoots that will affect the yield of sugarcane.

2.2.3 Stalk elongation phase

This phase will occur 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 to accumulate sugar.

2.2.4 Maturity and ripening phase

This phase has a slower growth rate compared to the other stages. When growth slows down, sugar from leaves produced from photosynthesis is less, and most of sugar is accumulated into stalk. At the beginning of maturing, sugar accumulation will start from the base to the tip. Therefore, the base is sweeter than the tip, the accumulation of sugar will increase accordingly until whole stalk with a similar sweetness (ripen).

2.3 Importance of water to plants

Water is a compound found in up to 3 in 4 of the earth. Most of them are in the salty conditions in the sea and ocean, about 97 percent are polar ice, and about 2 percent are snow. The fresh water along various canals is only about 1 percent. In agriculture, water is very important for plant growth. The water is an important element in various parts of plants and necessary for the physiological processes of plants. In natural conditions, 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 or that is lost from the transpiration. The conditions in which the water in the plant changes until it falls below an appropriate level, directly affects the physiological processes, growth, yield and quality of product. In addition, water also helps to dissolve minerals nutrient in the soil, so that the roots can absorb nutrient to the various parts of plant, and it also helps the soil to be moist that makes the various processes is normal in plant.

Sugarcane is a high water requirement crop compared to other field crops. Therefore, water is an important factor for the growth and productivity of sugarcane, because it is solvent for plant nutrient that affects yield and quality of sugarcane and can stimulate enzyme activity of seed germination. In the northeast region, there is 80 percent sugarcane planting area without irrigation, main relying on rainfall. Sugarcane cultivation in the northeast is planted mostly in late rainy season because the soil has sufficient moisture for germination. Department of Agriculture (2004) reported that sugarcane needed an average annual rainfall of 1,200–1,500 mm. In 2017, the planting area for sugarcane had an average annual rainfall of 1,452 mm approximately in the northeast (Office of the Cane and Sugar Board, 2018) where the amount of rainfall is deficiency for the growth of sugarcane. Each sugarcane variety has the ability to adapt to different soil types and environments. Sansayawichai et al. (2003) reported that irrigation rate should be 40 percent of the evapotranspiration that had no different effects on yield compared with the full water supply in Satuk soil series. Paisancharoen et al. (2012) reported that an average yield of irrigated ratoon1 Khon Kaen 3 variety, with the highest amount of water about 1,566–1,654 mm per season will be 20.03–

21.07 tons/rai. While the half amount of water supply with 70.08–122.4 mm has a decrease in water use efficiency of 12.2–12.8 kg/rai/mm. Kaushal et al. (2012) reported that sugarcane was a plant that took quite a long time to create biomass. Therefore, it needs about 1,100–2,200 mm of water per season. Drip irrigation for sugarcane can increase water use efficiency 60–200 percent, save up water to 20–60 percent and increase yield and quality by as much as 7–25 percent compared to conventional irrigation. Therefore, the drip irrigation system has been used to increase the yield of sugarcane in agriculture. If sugarcane receives sufficient water throughout the growth period, the yield will be increased. The irrigation rate should be provided at 24 mm. When the evapotranspiration is 40 and 60 mm, the yield is higher than other treatments with 15.9 and 16.1 tons per rai, respectively (Kapetch et al., 2010). There was a comparison between drip irrigation system and double groove system, with sugarcane U Thong 3 variety using the recommended fertilizer application rate (12–6–12) in Kamphaeng Saen soil series, Suphan Buri Province in 2004/05 and 2005/06. It was found that the drip irrigation system was in accordance with the water requirement of plant, and that the water consumption was 1.25 times the water requirement of plant. The sugarcane had higher yield and quality. The average yield of sugarcane with irrigation was 19.75 tons/rai compared to rainfall with 16.13 tons/rai and average the yield of ratoon1 was of 18.69 tons/rai compared to 14.70 tons/rai (Kaewkhongkha et al., 2005).

2.4 Determination of plant water requirement

2.4.1 Water use of crop evapotranspiration (ETc)

Soil moisture can be controlled by water supply in plant roots zone between Permanent Wilting Point (PWP) and Field Capacity (FC) or during the humidity range when the plants absorb water easily. Tungsombun (2006) also reported that plants were able to absorb water easily when soil moisture decreases 50–70%. Soil moisture is allowed to reduction before next water supply that is called Allowable Depletion. Soil moisture content between capillary water and absorbed water after plants absorption is called Critical Point (Figure 2.1).

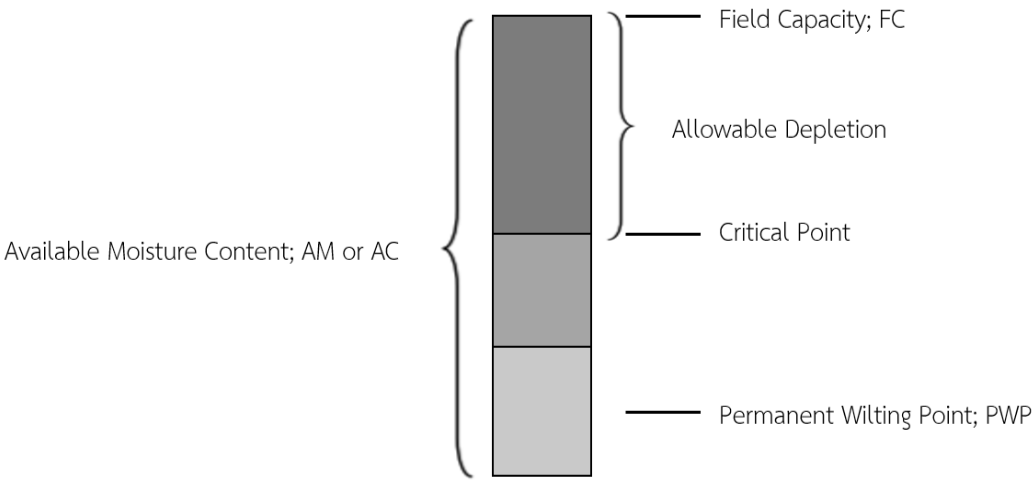

Figure 2.1 The relationship between soil moisture and determination the water of plants (Thongaram et al., 2002).

Generally, the amount of water supply should be according to water requirement of plant and WHC of soil that can be measured by using a device of moisture measuring, which is a sensor that used to measure 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 plant. Providing water to plants using the reference crop evapotranspiration can ensure soil moisture content as possible as closing to FC. Currently, there are various types of humidity sensors used for many plants but few used in sugarcane.

Sugarcane requires a lot of water for growth compared to other crops. Water is an important factor for growth and productivity of sugarcane. Providing appropriate irrigation in each growth phase will increase growth and yield of sugarcane. Shoot of sugarcane that is response to irrigation rate will be reduced obviously when the soil moisture is not enough. Kapetch et al. (2010) investigated the response of sugarcane to the water during various growth phases in Satuk soil series and found that the water deficiency in tillering phase caused a decrease in cane number and yield. Sansayawichai & Thanomsap (2006) suggested that water should be supplied precisely in germination phase and stalk elongation phase when there is duration of 170 days.

Determination of crop evapotranspiration using the climatic data is the easiest and most convenient way. Evaporation of surface will depend on properties of surface evaporate of water and climate defined as the evaporative demand. Therefore, the evaporated surface should be standardized, such as water surface or conversion of the plants that use water completely and the area covered. The evaporation of water from such surfaces only depends on climatic factor. Therefore, the climatological data can be used to predict evaporation of water that is calculated by three equations.

1) 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 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 showed as follows.

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

The ETc can be calculated from coversion 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 all times. The evaporation and transpiration can be affected by external factors, such as blowing the wind to required ETp or depending on climate change solely. In addition to the direct measurements, ETp also can be calculated from the climate at time and place of trial or place that will bring ETp to use in. There was a gathered ETp in the provinces where it is distributed monthly from climate data average 25 year (Thongaram et al., 2002).

2) 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 plant. The ETc equation is showed as follows.

$$\mathbf{ETc = Kp \times Epan \times Kc}$$

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

3) Class A Pan Evapotranspiration (Epan) and Class A Pan coefficient (K´p) The ETc equation is showed as follows.

$$\mathbf{ETc = K'p \times Epan \times Kc}$$

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

ETc calculated from climatic 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 that has been listed in Table 2.1 and Table 2.2.

From the Table 2.1, it is found that the Kc value is low during the first month and increases with sugarcane growth. The value decreases when sugarcane begins to accumulate sugar and stop the growth of stems, indicating that Kc value is depend on the age of the plant. Paisancharoen et al. (2012) found that in the sandy loam soil, Warin soil series, Khon Kaen province, the Kc values of ratoon1 Khon Kaen

3 variety were 0.69, 0.39, 0.84, 2.28 and 0.75 at the Initial phase (0–45 days), Dormancy phase (46–120 days), Tillering phase (121–225 days), Sugar accumulation phase (226–330 days) and Maturity and ripening (331–360 days), respectively. Da Silva et al. (2013) reported that the productivity of sugarcane was increased according to the increasing level of soil available water, and that the yield was 110.2–136.1 tons/ha obtained from the irrigation of 75 and 100% of ETo, respectively.

Table 2.1 The crop coefficient (Kc) value of crop (Royal Irrigation Department, 2011).

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	0.80	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
Average	0.76	0.90	0.92	0.82	0.91	0.85	1.01

Table 2.2 Potential evapotranspiration (ETp) of Penman–Monteith monthly in the northeast of Thailand (Royal Irrigation Department, 2011).

Province	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Nong Khai	3.1	3.8	4.6	4.6	4.0	3.6	3.5	3.4	3.5	3.6	3.3	3.0
Loei	3.3	4.1	4.8	5.1	4.4	4.1	3.7	3.6	3.6	3.6	3.2	3.0
– Royal Agricultural Station Loei	3.2	4.0	4.7	4.8	4.2	3.9	3.9	3.4	3.8	3.5	3.4	3.0
Udon Thani	3.3	4.1	4.9	5.2	4.6	4.1	3.7	3.6	3.6	3.7	3.7	3.2
Sakon Nakhon	3.4	4.1	4.9	5.0	4.4	4.0	3.6	3.4	3.9	3.9	3.6	3.3
– Royal Agricultural Station Sakon Nakhon	3.1	3.8	4.5	5.0	4.4	4.3	3.9	3.7	4.0	3.8	3.4	3.1
Nakhon Phanom	3.3	3.9	4.3	4.5	4.0	3.5	3.4	3.3	3.5	3.6	3.6	3.2

Table 2.2 Potential evapotranspiration (ETp) of Penman–Monteith monthly in the northeast of Thailand (Continued) (Royal Irrigation Department, 2011).

Province	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
– Royal Agricultural Station Nakhon Phanom	3.5	4.0	4.5	5.0	4.3	4.3	3.8	3.3	3.8	3.6	3.6	3.3
Khon Kaen	3.7	4.2	5.1	5.0	4.7	4.3	3.9	3.7	3.6	3.8	3.8	3.6
– Royal Agricultural Station Tha Phra	3.2	3.8	4.5	4.8	4.3	3.9	3.9	3.4	3.5	3.6	3.5	3.2
Mukdahan	3.7	4.2	5.0	5.2	4.1	3.6	3.6	3.4	3.6	3.8	4.0	3.5
Mahasarakham	3.6	4.2	4.7	5.2	4.6	4.2	3.8	3.6	3.6	3.8	3.8	3.6
Kalasin	4.2	4.9	5.4	5.5	4.8	4.3	4.2	3.7	3.7	4.1	4.3	4.1
Chaiyaphum	3.6	4.2	5.0	5.1	4.5	4.1	3.8	3.6	3.6	3.8	3.9	3.5
Roi Et	3.5	4.1	4.7	4.8	4.2	3.9	3.8	3.6	3.6	3.6	3.7	3.5
– Royal Agricultural Station Roi Et	4.0	4.4	4.9	5.3	4.6	4.6	4.2	3.9	3.6	3.8	4.1	3.9
Ubon Ratchathani	4.0	4.5	4.9	5.0	4.5	4.0	3.9	3.7	3.4	3.7	4.2	4.2
– Royal Agricultural Station Ubon Ratchathani	3.6	3.7	4.2	4.1	3.7	3.6	3.6	2.9	3.2	3.3	3.6	3.4
Srisaket	–	–	–	–	–	–	–	–	–	–	–	–
– Royal Agricultural Station Srisaket	3.4	3.9	4.6	4.8	4.4	4.4	4.2	3.7	3.9	3.6	3.8	3.5
Nakhon Ratchasima	3.4	4.0	4.4	4.6	4.2	4.0	3.9	3.8	3.4	3.4	3.5	3.4
– Royal Agricultural Station Pak Chong	4.7	4.7	5.0	4.8	4.2	4.5	4.3	4.0	3.4	3.5	4.4	4.5
Chokchai	3.5	4.2	4.7	4.7	4.1	4.2	3.8	3.7	3.3	3.6	3.6	3.4
Surin	3.8	4.4	4.8	4.9	4.2	4.1	3.7	3.6	3.6	3.7	3.8	3.8
– Royal Agricultural Station Surin	3.5	4.0	4.4	4.6	4.0	4.0	3.5	3.5	3.6	3.6	3.7	3.4
Tha Tum	3.5	4.2	4.8	5.0	4.4	4.0	4.0	3.5	3.6	3.7	3.9	3.6
Buriram	4.2	4.8	5.3	5.5	4.7	4.7	4.1	3.7	3.6	3.9	4.1	4.0
Nang Rong	3.6	4.2	4.8	4.9	4.4	4.0	3.9	3.6	3.6	3.8	3.9	3.6

2.4.2 Measuring soil moisture content

In present, there are various methods to measure soil moisture content accurately.

1) Soil water holding capacity (SWHC)

In the northeast of Thailand, most soil textures are loamy sand or sandy loam, with low fertility and SWHC that is affected by chemical, physical and biological properties of soil, which can help the soil to stock up on more nutrients. The water holding capacity in different soil textures has different critical points. Before planting, it is necessary to measure the SWHC and can be achieved by many methods using soil samples, such as gravimetric method and machine pressure plate. The rate of water supply for sugarcane can be calculated by analyzing the value of pressure plate. Different soil textures have different SWHC (Table 2.3 and 2.4).

Table 2.3 Soil water holding capacity in different soil textures (Thongaram et al., 2002).

Texture	Soil water holding capacity (mm water /cm soil)		
	Total	Available	Non-available
Sandy soil	0.65–1.50	0.35–0.85	0.30–0.65
Sandy loam soil	1.50–2.30	0.75–1.15	0.75–1.00
Loam soil	2.30–3.40	1.15–1.70	1.15–1.50
Clay loam soil	3.40–4.00	1.70–2.00	1.70–2.00
Sandy clay loam soil	3.60–4.15	1.50–1.80	2.10–2.35
Clay soil	3.80–4.15	1.50–1.60	2.30–2.55

Table 2.4 The physical properties of the soil related to moisture and available moisture that is between field capacity, permanent welting point (Thongaram et al., 2002).

Soil texture	AS	FC	PWP	Available Moisture		
				Aw (%)	Pv (%)	D (mm/cm soil)
	(1)	(2)	(3)	(4)=(2)-(3)	(5)=(4)x(1)	(6)=(4)x(1) x B/100
1. Sandy	1.65	9	4	5	8	0.8
	(1.55-1.80)	(6-12)	(2-6)	(4-6)	(6-10)	(0.6-1.0)
2. Sandy loam	1.50	14	6	8	12	1.2
	(1.40-1.60)	(10-18)	(4-8)	(6-10)	(9-15)	(0.9-1.5)
3. Loam	1.40	22	10	12	17	1.7
	(1.35-1.50)	(18-26)	(8-12)	(10-14)	(14-20)	(1.4-2.0)
4. Clay loam	1.35	27	13	14	19	1.9
	(1.30-1.40)	(23-31)	(11-15)	(12-16)	(16-22)	(1.6-2.2)
5. Silty clay	1.30	31	15	16	21	2.1
	(1.25-1.35)	(27-35)	(13-17)	(14-18)	(18-23)	(1.8-2.3)
6. Clay	1.25	35	17	18	23	2.3
	(1.20-1.30)	(31-39)	(15-19)	(16-20)	(20-35)	(2.0-3.5)

Note: (1) AS=Apparent Specific Gravity, (2) FC=Field capacity (% dry weight), (3) PWP= Permanent welting point (%Dry weight), (4) Aw=Available Moisture Content (%dry soil weight), (5) Pv=Available Moisture Content (%volume) and (6) D= Available Moisture Content (mm./cm.), B=depth of soil at 10 mm

2) Sensor system

Wireless sensor network (WSN) is a small sensor device used to measure the various properties of the environment, such as temperature, humidity and etc. It can digitize the environment around or respond the environment automatically through data processing. WSN is formed from a combination between embedded system of technology and wireless communications that transmit data between sensor nodes with ad–hoc formats. The highlight of the sensor network is based on the ad–hoc protocol, there is no need to install basic equipment for network as with WLAN or GSM networks.

In addition, the sensor node design is small size and low power consumption, allowing installation in various environments. Sensor network technology is expected a technology in pervasive computing by create an artificial environment. In this experiment, the watermark was chosen. The principle of the sensor is to read the moisture content from matric potential that there is directly related to soil moisture and displayed in kPa unit. If the soil has a lot of water, the soil water potential will be minimum. But when the soil has low moisture, the water potential is high. The sensor is displayed via a mobile phone connected to wireless sensor network. When soil moisture sensor reaches a critical value, the water supply must be returned to field capacity. Wonprasaid et al. (2021) reported that drip irrigation using soil moisture sensor values is a real–time water supply that was accurate and could increase water use efficiency by installing sensors to measure soil moisture at the roots zone of sugarcane at 20 and 30 cm of soil depth. Xie et al. (2020) found that using sensors to control irrigation reduced water by 10-80% compared to irrigation based on the water balance model. Masseroni et al. (2016) found that increasing the irrigation water use efficiency was a key factor for improving irrigation management and designed a system for soil water monitor. Pereira et al. (2020) reported that soil water balance (SWB) modeling with traditional models for real time irrigation scheduling, use of cloud and IoT technologies was developed into applications to the farm practice for precision agriculture.

- Principles and Operational Characteristics of the Watermark Sensor

The Watermark sensors (model 200SS) operate on the same principles as other electrical resistance sensors. Water conditions inside the Watermark sensor change with corresponding variations in water conditions in the surrounding soil. These changes within the sensor are reflected by differences in electrical resistance between two electrodes imbedded in the sensor. Resistance between the electrodes decreases with increasing soil water. In other electrical resistance sensors, plaster of paris, gypsum, glass fibers, ceramic, or nylon cloth has been used as the porous medium between the sensor and the surrounding soil, which is also known as the equilibrium medium. The Watermark is made of a porous ceramic external shell with an internal matrix structure containing two electrodes. In the newer design of the Watermark sensor, the matrix material is surrounded by a synthetic membrane for protection against deterioration and as a contact point with the soil. An internal cylindrical tablet buffers against soil salinity levels that occur in some irrigated soils. A synthetic porous membrane is surrounded by a stainless steel casing or sleeve with holes (Irmak et al., 2016). Watermark sensor will be measure moisture in the form of water potential related to the water use of plants, when the soil draws water with a force of 80 kPa, the plant can bring water to use. But if the soil pulls water with a force that is greater than 80 kPa, the plant will not be able to draw water from (Table 2.5). The advantages of watermark sensor, such as 1) watermark sensor is cheaper and requires less maintenance compared to EC-5 sensor 2) It is a measure of moisture with water pulling force. Making it compatible with all of soil types without having to measure soil moisture. 3) Negligible change in watermark sensor performance with variation in soil temperature. But there is a limitations, such as 1) users must have knowledge and understanding of the principles of watermark sensor so it can be used effectively. 2) It is low accurate in sandy soils because of their larger particle size (Zazueta & Xin, 1994).

Table 2.5 Depletion (in per foot) in available SWHC versus soil matric potential; AWHC; and suggested irrigation trigger points for different soil textures (Irmak et al., 2016).

Soil matric potential (kPa)	Soil type, depletion in inches per foot associated with a given soil matric potential value measured by the Watermark sensors, and available water holding capacity for different soil types							
	Silty clay loam topsoil, Silty clay subsoil (Sharps burg)	Silt-loam topsoil (Keith)	Upland silt loam topsoil, Silty clay loam subsoil (Hastings, Crete, Holdrege)	Bottom land Silt-loam (Wabash, Hall)	Fine sandy loam	Sandy loam	Loamy sand (O'Neill)	Fine sand (Valen tine)
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.20	0.30	0.30	0.30
33	0.20	0.14	0.00	0.00	0.55	0.50	0.45	0.55
50	0.45	0.36	0.32	0.30	0.80	0.70	0.60	0.70
60	0.50	0.40	0.47	0.44	1.00	0.80	0.70	0.70

Table 2.5 Depletion (in per foot) in available SWHC versus soil matric potential; AWHC; and suggested irrigation trigger points for different soil textures (Continued) (Irmak et al., 2016).

Soil matric potential (kPa)	Soil type, depletion in inches per foot associated with a given soil matric potential value measured by the Watermark sensors, and available water holding capacity for different soil types							
	Silty clay loam topsoil, Silty clay subsoil (Sharps burg)	Silt-loam topsoil (Keith)	Upland silt loam topsoil, Silty clay loam subsoil (Hastings, Crete, Holdrege)	Bottom land Silt-loam (Wabash, Hall)	Fine sandy loam	Sandy loam	Loamy sand (O'Neill)	Fine sand (Valen tine)
70	0.60	0.50	0.59	0.50	1.10	0.80	0.80	0.80
80	0.65	0.55	0.70	0.60	1.20	1.00	0.93	1.00
90	0.70	0.60	0.78	0.70	1.40	1.20	1.04	N/A
100	0.80	0.68	0.85	0.80	1.60	1.40	1.10	N/A
110	0.82	0.72	0.89	0.88	N/A	N/A	N/A	N/A
120	0.85	0.77	0.91	0.94	N/A	N/A	N/A	N/A
130	0.86	0.82	0.94	1.00	N/A	N/A	N/A	N/A
140	0.88	0.85	0.97	1.10	N/A	N/A	N/A	N/A
150	0.90	0.86	1.08	1.20	N/A	N/A	N/A	N/A
200	1.00	0.95	1.20	1.30	N/A	N/A	N/A	N/A
Water holding capacity (in/ft)	1.8-2.0	1.8-2.0	2.20	2.00	1.80	1.40	1.10	1.00
*Suggested range of irrigation trigger point (kPa)	75-80	80-90	90-110	75-80	45-55	30-33	25-30	20-25

(N/A: not applicable), (*)The trigger points were calculated with the assumption of no sensor malfunction.

- Tools for studying soil moisture

Tools for studying soil moisture by measuring some properties of soil that are related to the amount of water, which the popular tools are as follows

1) Gravimetric method is a standard method for soil moisture measurement. The soil samples are oven dried at 105–110^{o}C. The gravimetric soil moisture is calculated by Thongaram et al. (2002) as follows:

$$\text{Moisture (\%weight)} = \frac{\text{Wet weight-Dry weight}}{\text{Dry weight}} \times 100$$

2) Tensiometer is a measure of water potential by measuring tensile of the soil by using a tensiometer embed into the soil in the area that needs to be measured 3–4 days before measuring. This technique is suitable for measuring moisture from saturated to 8.5 bars.

- Principle of Tensiometer

The porous tip will be filled with water. The surface tension of the water that the contact surface between the water and air is a small hole in the gap. The water can flow through this channel that is connected to the water film surrounding the soil particles. When the soil is dry, the water film that surrounds the soil particles is thin and attached to soil particles with greater force. There will be the force to suck the water out of tensiometer through the porous tip causing the water in tensiometer to become more tension and this tension will rise until the water from the inside of tensiometer is stops. The water stress in the soil is equal t0 the tensiometer reading. On the other hand, if the soil is wet (may be due to rainfall or irrigation), the stress of water in the soil will decrease. While the stress of tensiometer is still high, the water will flow from the soil into the tensiometer via a hole in the porous tip. When the water tension in the soil is equal to the tensiometer, the water will stop flowing. The stress of water in the soil at moisture level can be read from the tensiometer as shown in Table 2.6.

Table 2.6 The meaning of value from the tensiometer (Kanchanaprasert et al., 2003).

Readable value	Mean
0	The saturated soil with water, very wet
0–15	Soil moisture is at of field capacity level, suitable moisture for plants that need high moisture.
25	The plants will begin to be water deficit.
>25	The plants are affected by water deficit, the plants grown in pots will begin to show water deficit. Especially, if it is coarse texture soils.
40–50	The root of plants depth 50 cm or more than will begin to water deficit.
70	The root of plants depth 75 cm or more than will begin to water deficit.
80	The plants should be irrigated in any case.

3) Moisture block, this method uses gypsum sticks consisting of two electrodes embed into the soil in the area that needs to be measured. The principle of reducing electrical conductivity when soil moisture decreases is a suitable measure for the moisture content of dry soil ranging from –0.5 to –15 bars. After the embedding of gypsum sticks in the soil about 1 week, the moisture in the gypsum is adjusted to the balance level of the soil. Therefore, measuring by using soil moisture tester and then draw a graph showing the changes in soil moisture compared to the amount of rain each month.

4) Neutron probe, the principle is to release the fast neutron radiation from the probe that is dropped into the ground in various depths. When this fast neutron radiation attaches hydrogen ions of water molecules or soil moisture, it will be changed to slow moving neutrons and reflect to probe. High readings show that there is a high amount of water in the soil. It is a tool that can measure soil moisture quickly and can be continuously measured.

2.5 Irrigation system

Suitable irrigation systems in an area are depended on many factors such as soil type, slope, cost, availability of water, availability of labor, and machine tools. Current irrigation systems that are used both in Thailand and abroad as follows.

2.5.1 Furrow irrigation

Furrow irrigation is an irrigation system that is widely used both in Thailand and abroad. Because it is a low-cost system, convenient and easy to practice but there are restrictions on the sugarcane plantation plot to be relatively smooth with a slope of not more than 3 percent. The efficiency of the irrigation will vary between 30-90 percent and increase efficiency providing water correct and proper management.

2.5.2 Sprinkler irrigation

This type of irrigation is applicable to all areas and all types of soil. Efficient use of water may exceed 75 percent if correct and proper management in provided. There are many types of water supply, such as a big springer that use a high-pressure water pump.

2.5.3 Drip irrigation

Drip irrigation is a method of providing high efficiency water used for planting almost all plants. The principle of drip irrigation is to apply water to the soil in the form of a cutting cone and allow the plant roots to grow within cone of moisture by maintaining the moisture in soil to be in field capacity all times. It can be applied in many types of plants. This method is popular, especially in situations that face water and labor shortage. There are 2 types of drip irrigation use in sugarcane fields.

1) Surface system, this system will place a drip tape or pipe on surface of the ground in the center of beside groove.

2) Subsurface system, the drip line will be install under subsoil surface before planting. Usually the buried depths are about 25-30 cm or under sugarcane stalk about 10 cm.

There are many advantages of drip irrigation systems such as 1) High water efficiency when compared to other methods 2) Suitable all types of area and soil, whether loam, sandy or clayey soils 3) Can be used with various types of plants, except plants that need water flooding 4) Suitable for water shortage areas or need to use water economically 5) Helps the plant have more roots and increase water and nutrients use efficiency (Raj et al., 2013) 6) Use less labor to apply water and can provide fertilizer and other chemicals such as pesticides along with water system. Fertilization via irrigation system can increase efficiency of fertilizer use of plants more than 80-90% (Thompson et al., 2003) 7) Controlling amount of water and fertilizer to even amount that the required by plants.

Limitations of drip systems such as 1) The equipment has a high price, complex mechanism, need high skill and knowledge and understanding of various equipment and maintenance 2) If the water is not clean, it will clog easily 3) Insects or biting animals damage.