CHAPTER IV
RESULTS AND DISCUSSION

4.1 Experiment 1: Controlling drip irrigation for sugarcane by water balance model.

4.1.1 Sugarcane growth parameter

4.1.1.1 Plant height

It was found that the plant height at 2 MAP was significantly different among the treatments, in contrast, the treatments did not significantly affect plant height at 4 and 6 MAP. At 2 MAP, full irrigation controlled by water balance model (T3) produced the highest plant height (18.8 cm) while the lowest plant height was found in rainfed conditions (T1) (15.4 cm). In addition, T3 tended to produce the highest plant height at 4 and 6 MAP (Table 4.1).

Table 4.1 Effects of irrigation methods on plant height.

Treatment	Plant height (cm)		
	2 MAP	4 MAP	6 MAP
T1: Control (rainfed conditions)	15.4^{b}	47.7	151
T2: Half water supply	16.6^{b}	53.7	160
T3: Full water supply	18.8^{a}	55.1	163
F-test	**	ns	ns
CV (%)	3.39	8.34	2.95

[1] Means in the same columns with different letters are significant differences based on DMRT at P < 0.05.

4.1.1.2 Shoot number

The results of shoot number are shown in Table 4.2, shoot number was not significantly different among the treatments at all months (2, 4, and 6 MAP). However, drip irrigation treatments (T2 and T3) tended to produce higher shoot numbers than in rainfed conditions.

Table 4.2 Effects of irrigation methods on shoot number.

Treatment	Shoot number (No./rai)		
	2 MAP	4 MAP	6 MAP
T1: Control (rainfed conditions)	17,627	36,267	17,320
T2: Half water supply	19,596	37,156	17,504
T3: Full water supply	20,933	42,489	17,877
F-test	ns	ns	ns
CV (%)	19.7	15.7	6.81

[1] Means in the same columns with different letters are significant differences based on DMRT at P < 0.05.

4.1.2 SPAD chlorophyll meter reading (SCMR)

Table 4.3 shows the SCMR, it was significantly different among treatments at 4 and 6 MAP. The SCMR was the highest at both MAP in T3 (39.1 and 42.0, respectively), while T1 produced the lowest SCMR at both MAP (36.0 and 38.1, respectively).

Table 4.3 Effects of irrigation methods on SCMR.

Treatment	SCMR (SPAD unit)	
	4 MAP	6 MAP
T1: Control (rainfed conditions)	36.0[b]	38.1[b]
T2: Half water supply	38.8[a]	38.6[b]
T3: Full water supply	39.1[a]	42.0[a]
F-test	*	*
CV (%)	2.52	2.63

[1] Means in the same columns with different letters are significant differences based on DMRT at P < 0.05.

4.1.3 Leaf nutrients analysis

The leaf nutrient analysis showed that leaf nitrogen was significantly different but phosphorus, potassium, and calcium were not significantly different between treatments. The highest nitrogen was found in T3 (1.82%) while the lowest was in T1. P, K, and Ca in irrigation treatments (T2 and T3) tended to be higher than in the rainfed practice.

In the comparison of the leaf analysis and the standard nutrient content, it was found that N and K in all treatments were lower than the standard nutrient content and P was comparable to the standard value. For Ca content, T3 was comparable but T1 and T2 were lower than the standard value (Table 4.4).

Table 4.4 Effects of irrigation methods on plant nutrients of leaf.

Treatment	N (%)	P (%)	K (%)	Ca (%)
T1: Control (rainfed conditions)	1.69^{bc}	0.22	0.80	0.17
T2: Half water supply	1.75^{ab}	0.24	0.80	0.20
T3: Full water supply	1.82^{a}	0.26	0.97	0.26
F-test	**	ns	ns	ns
CV (%)	3.20	19.6	15.6	29.4
Suitable nutrient content in sugarcane leaves	2.00-2.60	0.22-0.30	1.00-1.60	0.22-0.45

[1] Means in the same columns with different letters are significant differences based on DMRT at P < 0.05.

4.1.4 Yield and Yield components

The treatments significantly affected yield and stalk length, but not significantly different stalk diameter, and stalk weight. The highest yield was found in T3 (19.7 tons/ rai) while T1 produced the lowest yield (15.0 tons/ rai). The stalk length was the highest in T3 and lowest in T1 (296 and 260 cm, respectively.). The stalk diameter, stalk weight, and the number of millable canes (NMC) were not significantly different among treatments, but drip irrigation treatments (T2 and T3) tended to produce higher than those in rainfed conditions (T1).

Table 4.5 Effects of irrigation methods on cane yield.

Treatment	Yield (tons/rai)	Stalk length (cm)	Stalk diameter (cm)	Stalk weight (kg/stalk)	NMC (stalk/ rai)
T1: Control (rainfed conditions)	15.0^{b}	240^{b}	2.63	1.24	12,778
T2: Half water supply	16.5^{ab}	262^{b}	2.69	1.29	13,111
T3: Full water supply	19.7^{a}	296^{a}	2.73	1.35	14,444
F-test	*	**	ns	ns	ns
CV (%)	8.68	3.78	3.28	5.75	13.9

[1] Means in the same columns with different letters are significant differences based on DMRT at P < 0.05.

This experiment was conducted to compare the effects of 2 drip irrigation methods (half water supply and full water supply) and rainfed conditions on sugarcane. Both irrigation methods resulted in the improvement of sugarcane growth. The significant difference of plant height occurred between treatments at 2 MAP i.e., the rainfed treatment had the lowest plant height. Less significant differences were observed at 4 and 6 MAP, however, fully water supply still produced the highest plant height while rainfed conditions produced the lowest. Normally, in the northeast conditions, the first period of sugarcane planting is in the period of low rainfall which rainfed sugarcane always faces severe water limitation. The drip irrigation can provide water to meet sugarcane requirement during this period and enhances plant height. The next 4-6 MAP, the rainy season starts, causing the plants in the rainfed treatment to begin to recover from the water deficit but could not reach it's potential. The results were similar to Kapetch et al. (2010) and Khonghintaisong et al. (2017) who reported that when sugarcane experienced drought in early period, plant height significantly decreased and when the rain was recovered to normal conditions in later growth period, the sugarcane partially recovered. Both drip irrigation treatments also produced higher shoot numbers than the rainfed treatment. Similar result was reported by Paisancharoen et al. (2012) who showed that irrigation increased the shoot number at the average of 9,718-12,128 stalk/rai. The plant height and shoot number are important growth characters to predict the sugarcane yield that can be produced.

Beside plant height and shoot number, the SCMR and leaf N content also responded to irrigation. The results showed that full water supply had the highest SCMR and nitrogen content. According to Denise et al. (1995) report, it is a possible role in using a SPAD meter to estimate foliar N status in the field. In other words, the SCMR is high, it indicates that the sugarcane has a high nitrogen content. Peng et al. (1995) reported that the SCMR in plant leaves was an indicator of increased chlorophyll concentrations and higher levels of nitrogen fertilization resulted in higher SCMR values. Siriyoot & Jongkaewwattana (2011) reported that the increase in SCMR resulted in increased biomass dry weight and productivity. From the experiment results and previous reports, it can be implied that well irrigation can enhance N uptake resulting to increased chlorophyll content and consequently enhance growth and productivity.

The sugarcane yield and yield components were different among the irrigation methods. Fully water supply (T3) produced the highest stalk length, stalk diameter, stalk weight, NMC and yield while control treatment produced the lowest of all parameters. The results were similar to other studies such as Wonprasaid et al. (2021) who found that drip irrigation produced higher yield (17.8-22.3 tons/rai) than the rainfed condition (14.9 tons/rai). Paisancharoen et al. (2012) reported that full irrigation can yield 1st ratoon cane of CV. KK3 in an average of 20.0-21.1 tons/rai and Suphakarn et al. (2012) also reported that sugarcane CV. KK3 had a high stalk length (286 cm) under irrigation. Kruangpatee et al. (2017) showed that sugarcane yield was related to four yield components i.e., NMC, stalk weight, stalk length, and stalk diameter. In comparison of the irrigation methods between full water supply (T3) and half water supply (T2), it was found that full water supply could increase sugarcane yield more than half water supply. For half water supply, sugarcane received water only half amount of the full water supply, it is still insufficient water to meet the demand, therefore it's growth and yield was lower than it's potential. The results were similar to other studies. Thanomsub & Sansayawichai (2009) reported that the irrigation application at evapotranspiration (E) 60 mm produced the highest yield of 17.2 tons/rai while E 120 mm produced yield of only 13.9 tons/rai. In their study, at E 60 mm and E 120 mm, the irrigation was applied 20 and 10 times respectively throughout the growing season. Puengpa & Boontham (2012) reported that sugarcane growth and yields were positively correlated with the appropriate amount of watering of sugarcane. Even though half water supply produced lower yield than full water supply, it still can be recommended to farmers who have limited amount of reserved water as it still produced high and reliable yield compared to rainfed sugarcane.

4.2 Experiment 2: Growth and physiology study of Khon Kaen 3 sugarcane cultivated under irrigated and water deficit conditions.

4.2.1 Growth parameter

4.2.1.1 Plant height

The result showed that at stress period 1, the water deficit conditions at 3 months (T2) produced the lowest plant height, while the non-stress treatments (T1 and T3) produced similar plant height (Figure 4.1). At stress period 2, T2 still had lower plant height than irrigation treatment (T1), and the water deficit condition at 7 months (T3).

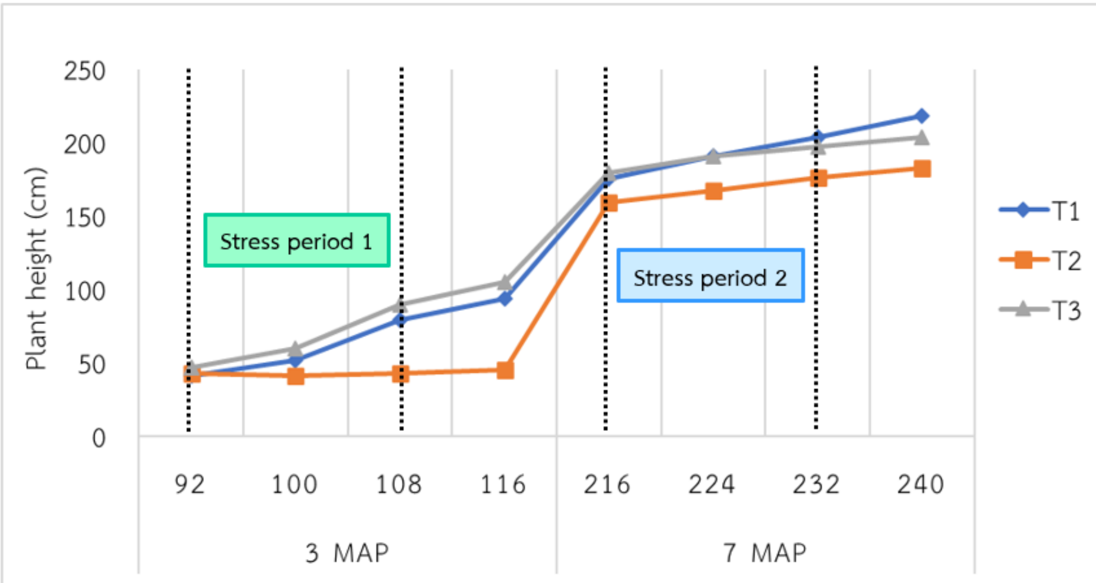

Figure 4.1 Effects of irrigation methods on plant height.

4.2.1.2 Shoot number

The results of shoot number are shown in Figure 4.2. During stress period 1, T2 tended to produce higher shoot numbers than irrigation treatment (T1) and the water deficit conditions at 7 months (T3). In contrast, irrigation treatment (T1) tended to produce higher shoot numbers than water deficit treatments (T2 and T3) during stress period 2.

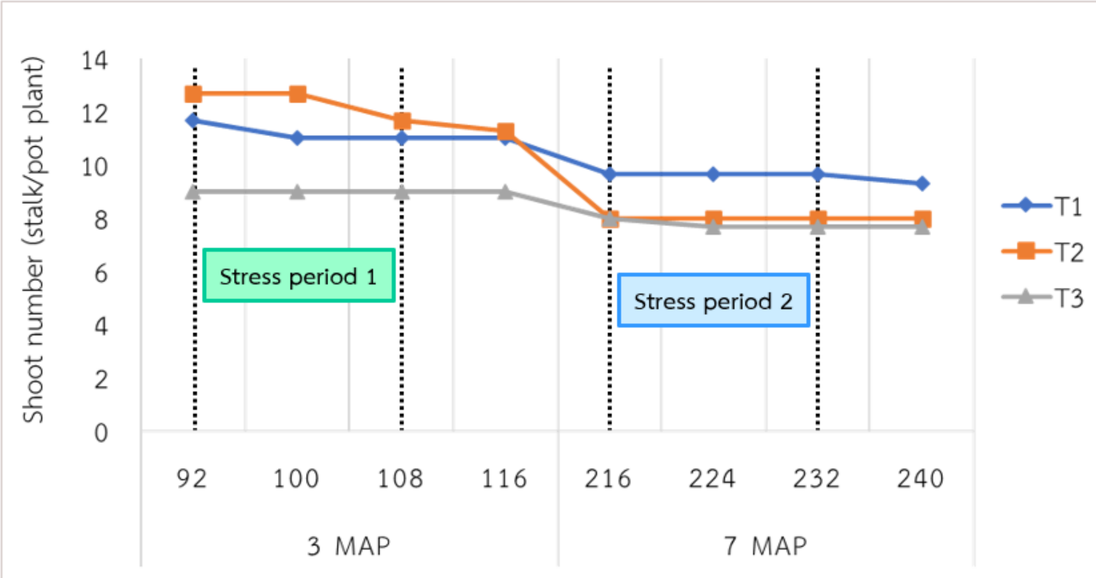

Figure 4.2 Effects of irrigation methods on shoot number.

4.2.1.3 Number of leaves

During stress period 1, irrigation treatment (T1) tended to produce a higher number of leaves, while the lowest number of leaves was found in T2. In contrast, in stress period 2 water deficit (T3) tended to produce the lowest number of leaves, while the irrigation treatments (T1) produced the highest number (Figure 4.3).

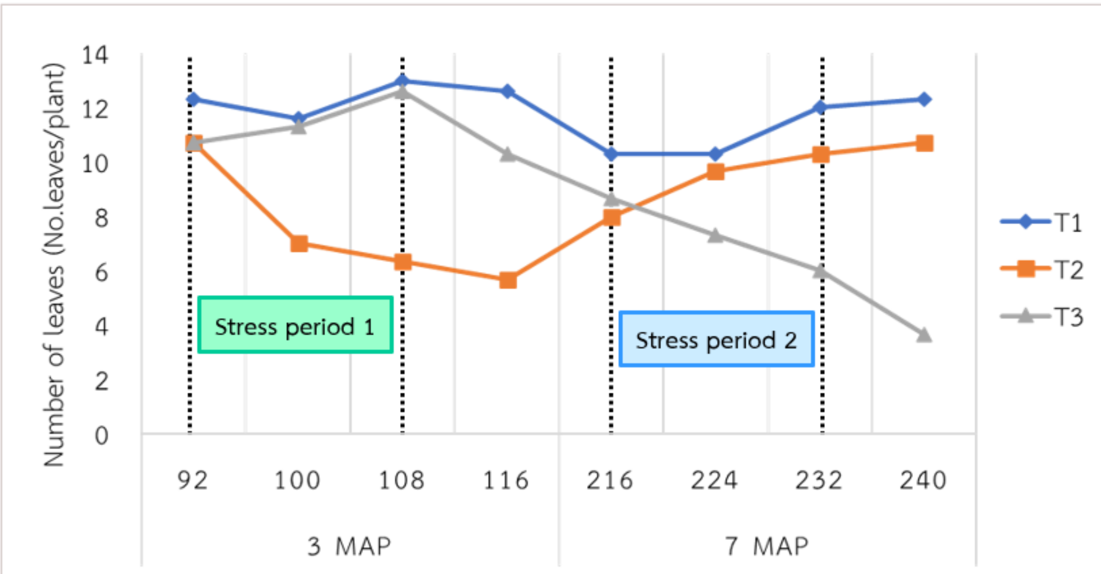

Figure 4.3 Effects of irrigation methods on the number of leaves.

4.2.2 Physiological process

4.2.2.1 SCMR

The SCMR result is shown in Figure 4. During stress period 1, irrigation treatment (T1) tended to have the highest SCMR values, while T2 had the lowest values. During stress period 2, the water deficit at 7 MAP (T3) produced the lowest SCMR, while the water deficit at 3 MAP (T2) had similar SCMR values to irrigation treatments (T1) (Figure 4.4).

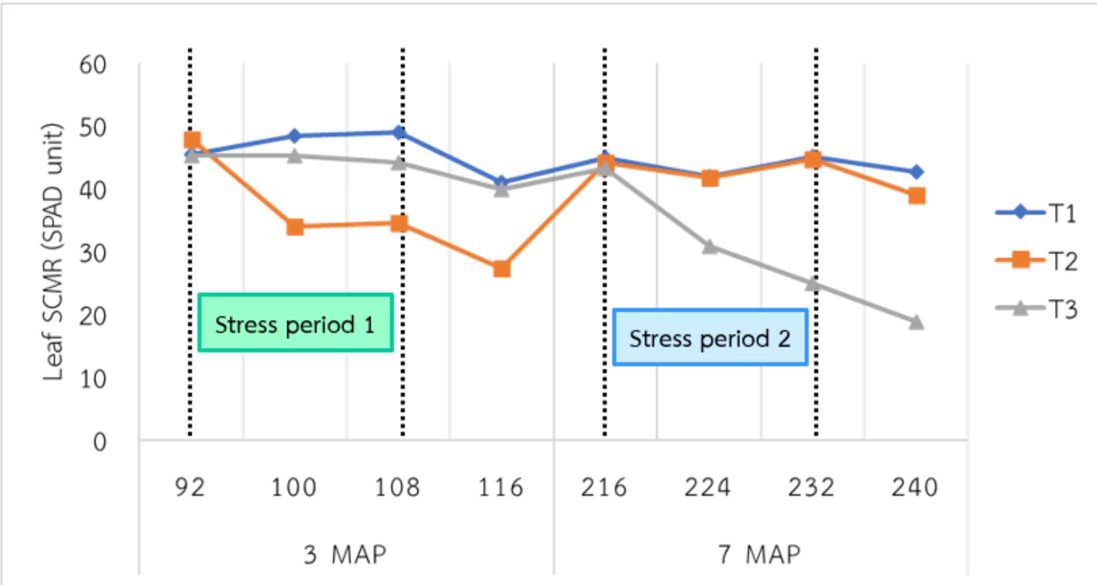

Figure 4.4 Effects of irrigation methods on SCMR.

4.2.2.2 Leaf water potential (LWP)

T2 had lower LWP than T1 and T3 at stress period 1. During stress period 2, water deficit at 7 MAP (T3) had the lowest LWP, while the water deficit at 3 MAP (T2) and irrigation treatments (T1) had similar higher LWP (Figure 4.5).

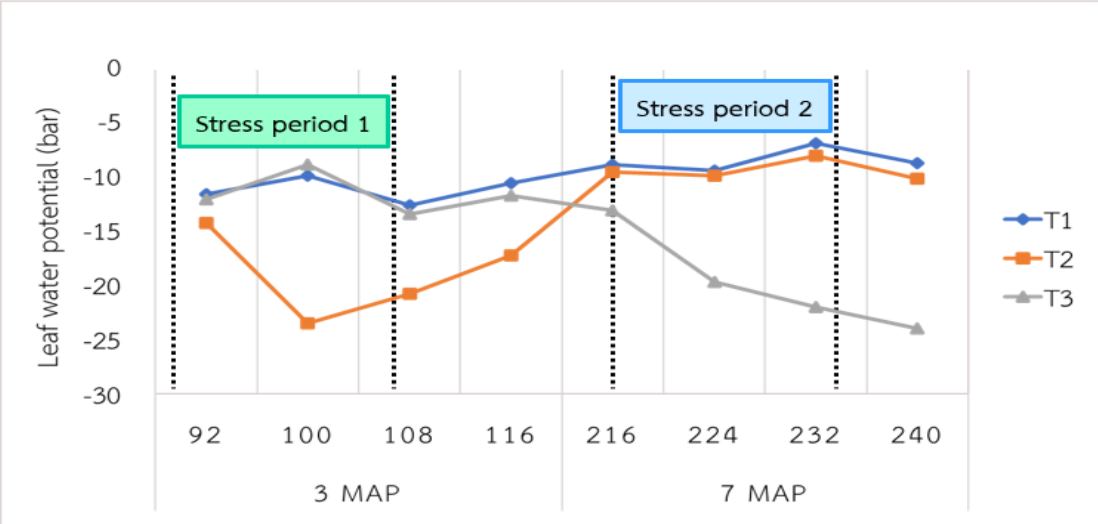

Figure 4.5 Effects of irrigation methods on leaf water potential.

4.2.2.3 Photosynthetic rate

The measurement of leaf photosynthetic rate of sugarcane found that T2 tended to produce a lower photosynthetic rate than irrigation treatment (T1), and the water deficit at 7 MAP (T3) during stress period 1. While at stress period 2, irrigation treatment (T1) tended to produce a higher photosynthetic rate than water deficit treatments (T2 and T3) (Figure 4.6).

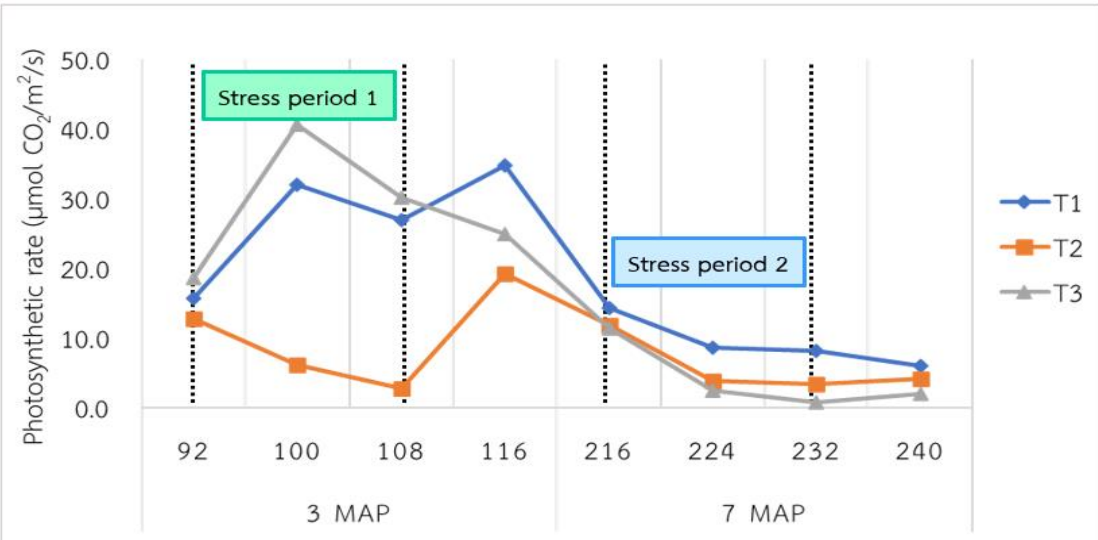

Figure 4.6 Effects of irrigation methods on the photosynthetic rate.

4.2.2.4 Transpiration rate

The result of transpiration rate measurement showed that at stress period 1, T2 produced a lower transpiration rate than irrigation treatment (T1), and the water deficit at 7 MAP (T3). While, at stress period 2, irrigation treatment (T1) tended to produce the highest transpiration rate compared to water deficit treatments (T2 and T3) (Figure 4.7).

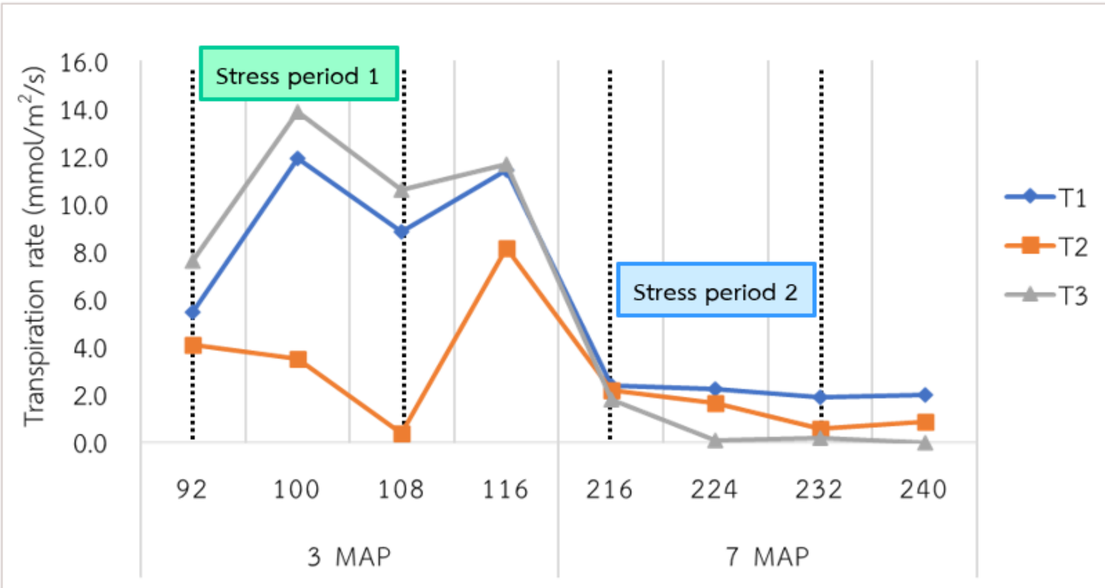

Figure 4.7 Effects of irrigation methods on transpiration rate.

4.2.2.5 Stomatal conductance

The result of leaf stomatal conductance measurement found that, at stress period 1, water deficit at 3 MAP (T2) had lower stomatal conductance than irrigation treatment (T1) and the water deficit at 7 MAP (T3). While during stress period 2, the irrigation treatment (T1) and water deficit at 3 MAP (T2) produced higher stomatal conductance than water deficit treatments (T3) (Figure 4.8).

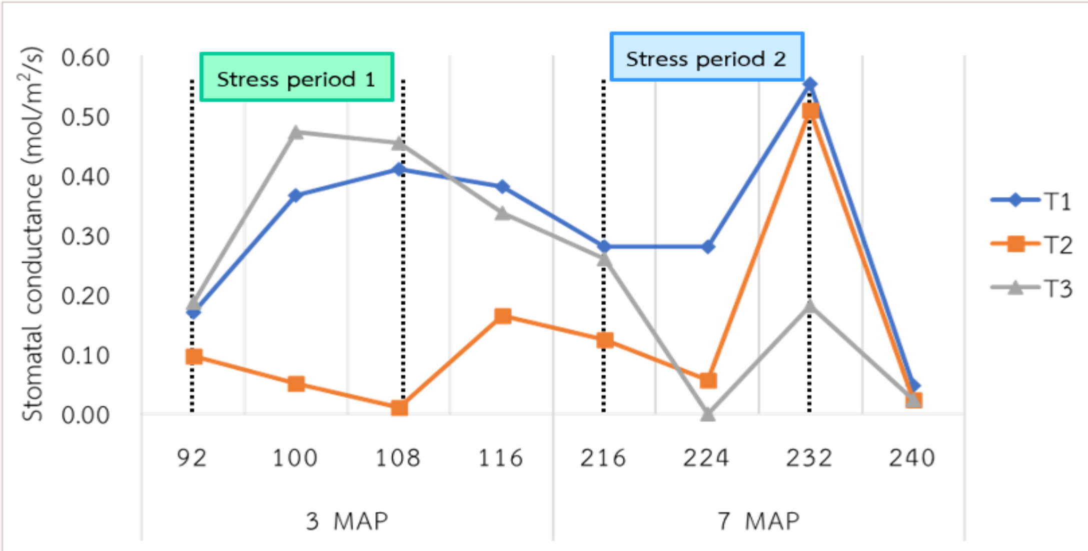

Figure 4.8 Effects of irrigation methods on stomatal conductance.

4.2.3 Yield and Yield components

The yield and yield components analysis is shown in Table 4.6, T1 produced the highest yield (11.8 kg) while T3 produced the lowest yield (7.73 kg). The stalk length, NMC, stalk weight, and total soluble solids (TSS) were not significantly different among treatments, but irrigation treatment (T1) tended to produce higher values than those in water deficit conditions (T2 and T3).

Table 4.6 Effects of irrigation methods on cane yield.

Treatments	Yield (kg)	Stalk length (cm)	Stalk diameter (cm)	NMC (stalk/ pot plant)	Stalk weight (kg/ stalk)	TSS (°Brix)
T1 Irrigation (Control)	11.8^{a}	230	2.75^{ab}	9.00	1.39	21.9
T2 water deficit conditions at 3 MAP	8.17^{ab}	206	2.65^{b}	7.00	1.18	21.6
T3 water deficit conditions at 7 MAP	7.73^{b}	185	3.00^{a}	7.00	1.11	20.1
F-test	*	ns	*	ns	ns	ns
CV (%)	15.6	9.23	3.24	7.53	22.4	10.9

[1] Means in the same columns with different letters are significant differences based on DMRT at P < 0.05.

This experiment was conducted to compare the effects of 2 water deficit methods (water deficit conditions at 3 and 7 months) and full irrigation under greenhouse conditions. Different irrigation methods resulted in growth and yield differences. Plant height tended to be the lowest in water deficit conditions at 3 MAP (T2) while the irrigation (T1) and water deficit conditions at 7 MAP (T3) tended to produced similarly higher plant height at this period. The effects of water deficit in the early growth stage, cause plants to halt their growth in many aspects. According to Khonghintaisong et al. (2017) research, it was found that during the water deficit in the early growth stage (90-135 DAP), KK3 cultivar had a decrease in the rate of daily height increment, especially during 105-120 DAP. Since this experiment was systematic management of the water supply under the greenhouse, the weather conditions didn't affect growth. The KK3 cultivar showed a decreased growth in both plant height and shoot number when faced the water deficit (Khonghintaisong et al., 2017). During stress period 1, especially during the first 3-4 months, as the soil moisture in the pots gradually decreased, competition between the plants cane, affected tillering and leaf production. The plant-maintained balance in the plant by dropping the leaves, causing reduced leaf production. The results were similar to Kapetch et al. (2010) who reported that during the soil receiving insufficient moisture content, the number of shoots per rai of no irrigation treatment was reduced more than in other irrigation methods and the value had relatively stable until harvesting. Ethan et al. (2016) also reported that the deficit irrigation at the mid-season stage had the greatest impact on sugarcane yield as the NMC at harvesting had reduced by 18.6% compared to full irrigation treatment. Endres et al. (2018) reported that the effect of water deficit mostly affected the leaf number of sugarcane during the early growth stage. During stress period 2, water deficit conditions at 7 months (T3) (the elongation stage), the number of shoots had reduced only slightly, but it had the greatest impact on productivity. When returning to the irrigation, the number of shoots increased slightly but it had the greatest impact on the NMC at harvest. The results were similar to Dingre & Gorantiwar (2021) who reported that water deficit in the elongation stage had the greatest impact on yields. Mall et al. (2016) also reported that one of the key growth phases affecting sugarcane yield was the elongation stage. Hsiao (1973) reported that water deficit primarily affected leaf formation and stem elongation.

The SCMR is the tool that indirectly detect the chlorophyll content and leaf nitrogen status. Jangpromma et al. (2010) found that the SCMR was a rapid tool for chlorophyll detectors. Nageswara Rao et al. (2001) and Richardson et al. (2002) found that leaf chlorophyll positively related to leaf nitrogen. In this study, the result showed that drought stress conditions at an initial stage (T2) and elongation stage (T3) had lower leaf SCMR than under the water-sufficient conditions (T1). A similar result of Arunyanark et al. (2009) found that drought stress influenced SCMR and Jangpromma et al. (2012) also found that the drought condition was an impact factor to reduce the chlorophyll content.

For physiological traits analysis (photosynthesis, transpiration, and stomatal conductance) and leaf water potential, the result showed that the lowest physiological traits, and LWP were found in drought stress at an early stage (T2) and elongation stage (T3). However, under rewatering conditions, sugarcane could recover by increasing the physiological traits and LWP more than under drought stress conditions but still did not recover up to the level of water-sufficient conditions. The result was similar to De Almeida Silva et al. (2011) and Dos Santos et al. (2014) who found that the water deficit condition was negatively related to photosynthesis, stomatal conductance, water transpiration, and leaf water potential. Chen et al. (2012) and Jongdee et al. (2002) also found that the water stress conditions which limited the available water in the soil had an effect of reducing sugarcane LWP.

The sugarcane yield and yield components of the water deficit and full irrigation methods were different. Full irrigation treatment (T1) produced the highest stalk length, stalk weight, NMC, TSS, and yield while water deficit treatment produced the lowest of all parameters. Similar result was reported by Ethan et al. (2016) who showed that the highest stalk height of 207.4 cm was found in full irrigation while the lowest stalk height of 189.4 cm was found under drought stress in the mid-season stage and sugarcane yield of 11.9 tons/rai was found under water deficit during the mid-season stage and yield of 15.7 tons/rai was found under fully irrigation treatments.

Soil moisture during 1-2 MAP was sufficient in all treatments as the same amount of water calculated at FC value was given to the sugarcane at the beginning in all treatments. However, after applying the water deficit conditions at 3 month (tillering stage) and 7 months (stalk elongation stage) resulted to the reduction of sugarcane growth in that period due to stress conditions but when returning to the irrigation, sugarcane could recover in both stress phases but was still not equivalent to the full irrigation treatment causing the reduction of final cane yield in both stress treatment comparing to full irrigation treatment. The results were similar to other studies by Doorenbos et al. (1980) who reported that water stress during the germination stage, tillering stage, and elongation stage were most sensitive to yield, and the maturation phase was least sensitive to water stress. Rossler et al. (2013) reported that water stress during the stalk elongation phase reduced cane yield by 6-11 tons/ha (5-9 %). Puengpa & Boontham (2012) reported the appropriate amount of soil water in each stage of the sugarcane growth period especially at the elongation stage was a positively correlated to sugarcane growth and yield.

4.3 Experiment 3: Controlling drip irrigation for sugarcane by the wireless sensor system.

4.3.1 Water requirement and water supply of sugarcane

4.3.1.1 Monthly water requirement and water supply

The monthly water requirement and water supply for sugarcane production in SCL soil and LS soil are shown in Figures 4.9 and 4.10 respectively. The monthly water requirement increased with the age of sugarcane and reached the maximum value of 185 mm in June in SCL soil and May in LS soil, after that the water requirement decreased until harvest.

The rainfall pattern was similar in both soils in which the highest rainfall of 195 and 292 mm appeared in September and August in SCL soil and LS soil respectively.

The amount of water supply was calculated according to the water requirement of sugarcane and the effective rainfall which was estimated by the Daily

Soil Moisture Balance Method (FAO, 1998). Normally sugarcane requires the water supply for ten months throughout the year. The highest water supply given to the SCL soil was 145 mm in April, but to the LS soil was 158 mm in June. There were relationships between rain, water requirement, and water supply. When the total water requirement of sugarcane was explicit, the more rainfall, the less water supply. Therefore, the water supply is dependent on the weather conditions in the growing season of each area.

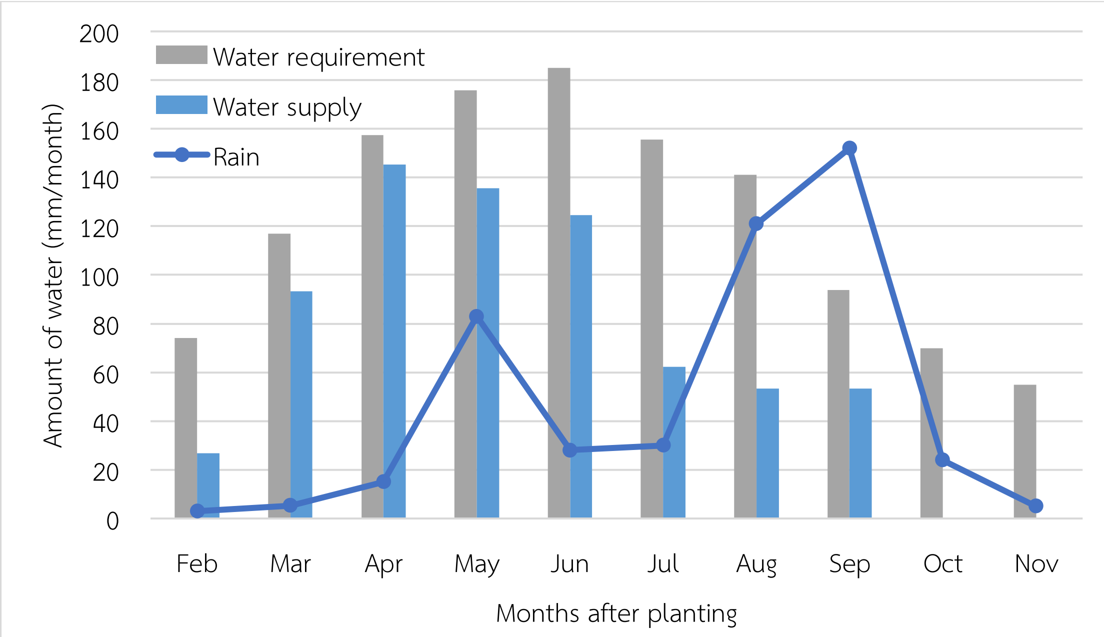

Figure 4.9 Water requirement and water supply of sugarcane in SCL soil during the planting season 2019/20.

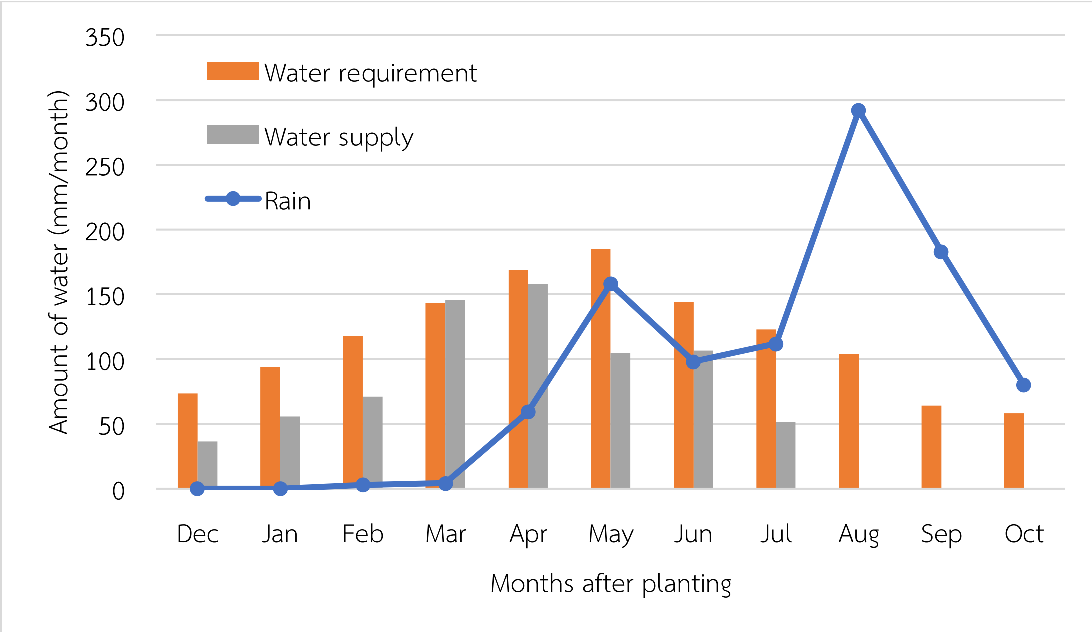

Figure 4.10 Water requirement and water supply of sugarcane in LS soil during the planting season 2018/19.

4.3.1.2 Total water requirement and water supply

The total water requirement and water supply are shown in Table 4.7 for SCL soil and Table 29 for LS soil. In SCL soil, sugarcane had a water requirement of 1,224 mm, but during the growing period, the average rainfall was only 253 mm, which was insufficient for the requirement of sugarcane. Therefore, the drip irrigation system irrigated the sugarcane to receive sufficient water to meet the requirements. The drip irrigation controlled by the water balance model (T2-T3) was irrigated 19 times with total irrigation water of 694 mm and the drip irrigation system controlled by the sensor (T4) was irrigated 14 times with total irrigation water of 548 mm. The result demonstrated that T4 used less irrigation water than T2 and T3. In contrast, T4 was the higher yield and yield component in this soil.

Table 4.7 Effects of irrigation methods on water total water requirement and water supply in SCL soil.

Treatment	Rainfall (mm)	Effective rainfall* (mm)	Irrigation water (mm)	Water requirement (mm)	Amount of water received ** (mm)	Number of irrigation supply
T1	466	253	-	1,224	253	-
T2	466	253	694	1,224	947	19
T3	466	253	694	1,224	947	19
T4	466	253	548	1,224	801	14

T1 = Control, T2 = Drip irrigation + water balance model + Soil fertilizer, T3 = Drip irrigation + water balance model + Fertigation, T4 = Drip irrigation + sensor + Fertigation

* Effective rainfall estimated by Daily Soil Moisture Balance Method

** Amount of water received = Effective rainfall + Irrigation water

In LS soil, sugarcane had a water requirement of 1,276 mm, but the average rainfall was 530 mm., which was also insufficient. The drip irrigation controlled by the water balance model (T2-T3) was irrigated 22 times with total irrigation water of 729 mm, while the drip irrigation controlled by the sensor (T4) was irrigated 17 times with total irrigation water of 640 mm. Similar to SCL soil, in this soil T4 also used less irrigation water (Table 4.8) and the yield was also higher than T2 and T3.

Table 4.8 Effects of irrigation methods on water total water requirement and water supply in LS soil.

Treatment	Rainfall (mm)	Effective rainfall* (mm)	Irrigation water (mm)	Water requirement (mm)	Amount of water received ** (mm)	Number of irrigation supply
T1	990	530	-	1,276	530	-
T2	990	530	729	1,276	1,259	22
T3	990	530	729	1,276	1,259	22
T4	990	530	640	1,276	1,170	17

T1 = Control, T2 = Drip irrigation + water balance model + Soil fertilizer, T3 = Drip irrigation + water balance model + Fertigation, T4 = Drip irrigation + sensor + Fertigation

* Effective rainfall estimated by Daily Soil Moisture Balance Method

** Amount of water received = Effective rainfall + Irrigation water

4.3.2 Soil water potential during the growing season of sugarcane

4.3.2.1 Soil moisture content of all treatments

The average soil water potentials at the depth of 20 - 40 cm from April to July in SCL soil and from March to June in LS soil are shown in Figures 4.11 and 4.12 respectively.

In SCL, the irrigation treatments (T2-T4) had the level of soil water potential mostly between the field capacity (FC) and critical point of the soils (-30 to-90 centibar). In contrast, T1 had lower soil water potential than the critical point (-90 centibar) except after rainfall events (Figure 4.11). Similarly, in LS soil, the soil water potential (T2-T4) was mostly in the available water holding capacity range and T1 had the lowest soil water potential (-196 centibar), which was below the critical point (-90 centibar) (Figure 4.12).

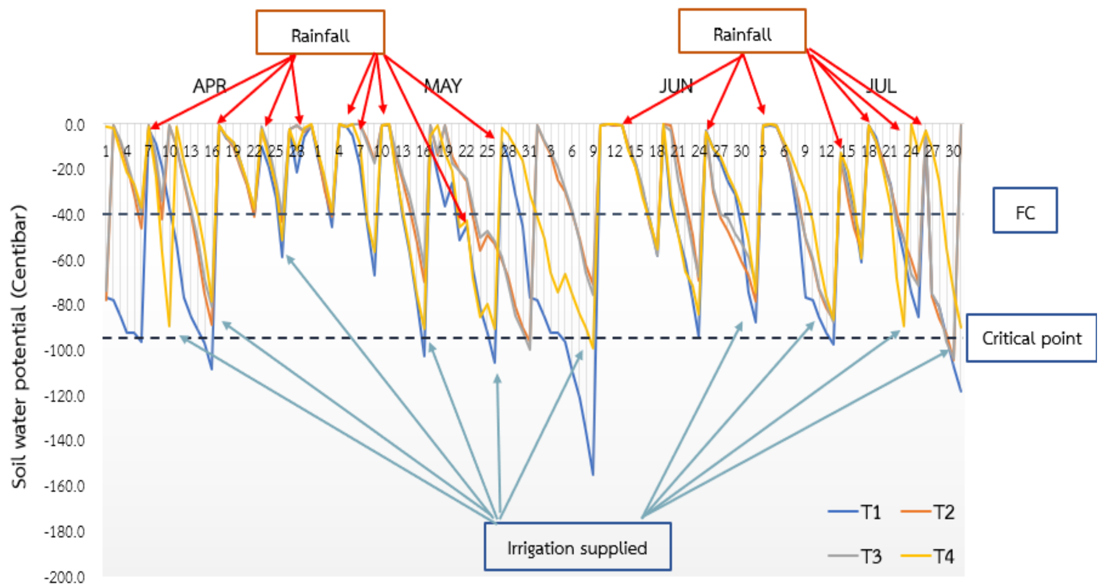

Figure 4.11 Effect of irrigation method on the humidity in SCL soil.

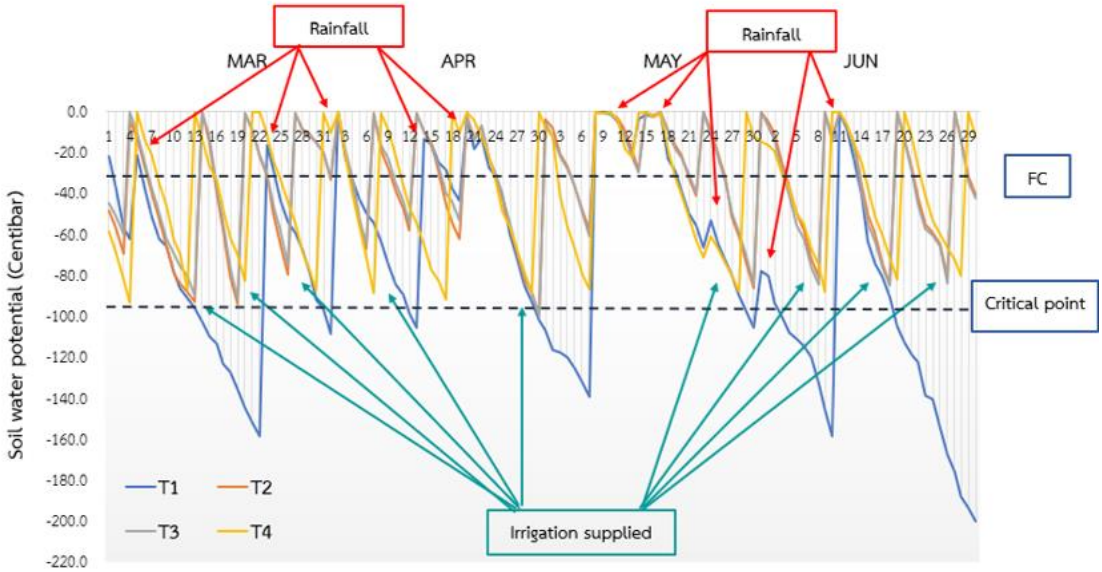

Figure 4.12 Effect of irrigation method on the humidity in LS soil.

4.3.2.2 Comparison of soil water potential between irrigation controlled by the water balance model and by a wireless sensor

Figures 4.13 and 4.14 show the comparison of soil water potential between T3 and T4 in SCL and LS soil. The irrigation treatment (T3-T4) had soil water potential mostly in the range between FC and critical point. However, they had different patterns of soil moisture during the monitoring period leading to different water supply patterns and amounts. T4 had less irrigation water supply than T3. In T4, the water application was based on the direct measurement of soil moisture using a watermark sensor which should be more accurate. While in the irrigation controlled by the water balance model (T3), the water application was based on indirect estimated soil water content. In this method, the soil moisture was estimated from water application, rainfall, and crop evapotranspiration (ETc) which was calculated from the historic weather conditions and crop coefficient (Kc). Therefore, the estimated soil water content might not be as accurate as the direct measurement in T4.

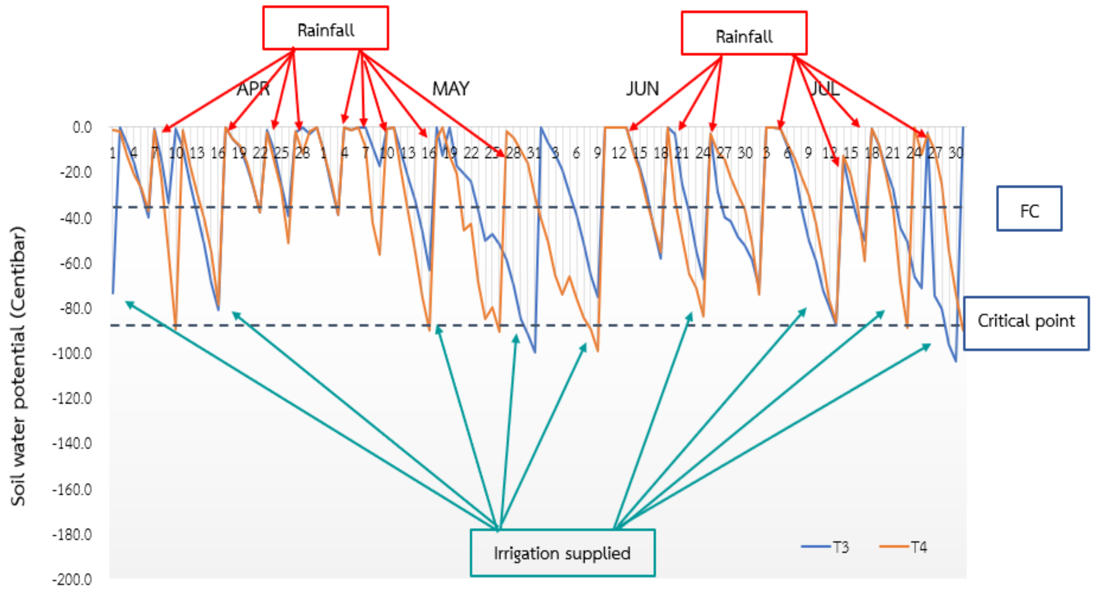

Figure 4.13 Comparison of soil water potential between irrigation controlled by water balance model and by a wireless sensor in SCL soil.

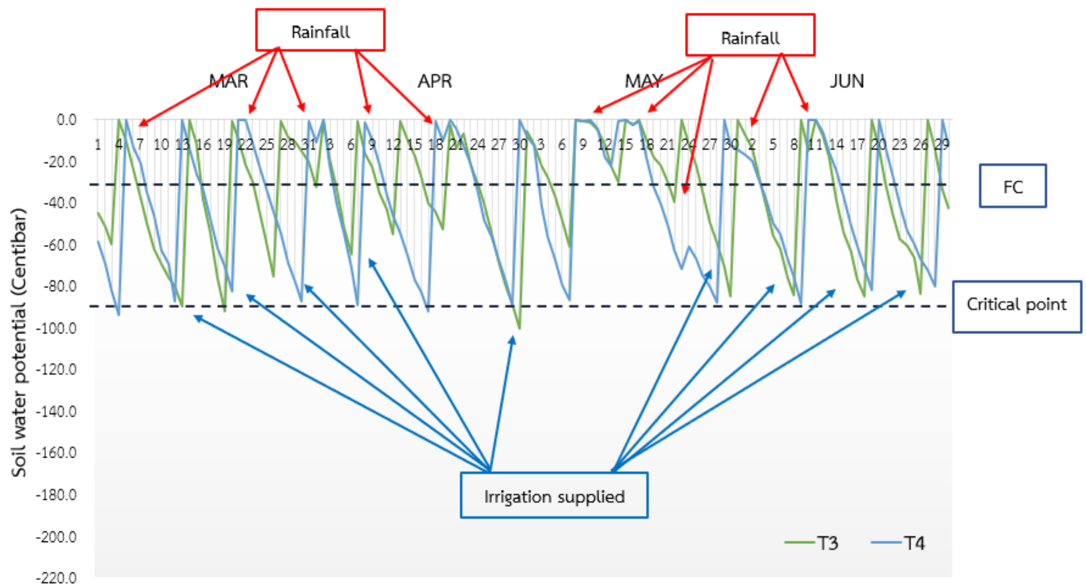

Figure 4.14 Comparison of soil water potential between irrigation controlled by water balance model and by a wireless sensor in LS soil.

4.3.3 Sugarcane growth

4.3.3.1 Plant height

In SCL soil, it was found that plant height in irrigation treatments (T2-T4) was significantly greater than those in no irrigation treatment (T1) at all MAP. Among irrigation treatments, plant height was statistically different. T4 was the highest plant height at all MAP (Table 4.9).

Table 4.9 Effects of irrigation methods on plant height in SCL soil.

Treatment	Plant height (cm)		
	2 MAP	4 MAP	6 MAP
T1: Control	23.7[c]	77.9[b]	116[b]
T2: Drip irrigation + WB model + Soil fertilizer	28.7[b]	110[a]	158[a]
T3: Drip irrigation + WB model + Fertigation	31.1[ab]	109[a]	161[a]
T4: Drip irrigation + sensor + Fertigation	33.0[a]	113[a]	165[a]
F-test	**	**	**
CV (%)	5.79	6.98	7.53

[1] Means in the same columns with different letters are significant differences based on DMRT at $P < 0.05$.

In LS soil, it was found that plant height in irrigation treatments (T2-T4) was also significantly greater than those in no irrigation treatment (T1) at all MAP. Among irrigation treatments, plant height was significantly different only at 2 and 4 MAP. T2 produced the highest plant height at 2 and 4 MAP, while at 6 MAP, plant height was not significantly different among irrigation treatments (Table 4.10).

Table 4.10 Effects of irrigation methods on plant height in LS soil.

Treatment	Plant height (cm)		
	2 MAP	4 MAP	6 MAP
T1: Control	9.5[c]	23.8[c]	147[b]
T2: Drip irrigation + WB model + Soil fertilizer	18.6[a]	48.8[a]	192[a]
T3: Drip irrigation + WB model + Fertigation	13.2[bc]	37.7[b]	171[a]
T4: Drip irrigation + sensor + Fertigation	14.3[b]	36.4[b]	194[a]
F-test	**	**	*
CV (%)	17.0	17.3	8.08

[1] Means in the same columns with different letters are significant differences based on DMRT at $P < 0.05$.

4.3.3.2 Shoot number

In SCL soil, the shoot number in drip irrigation treatments (T2-T4) was significantly higher than those in control (T1) at 2 MAP. Among irrigation treatments, shoot number was statistically different in which T4 produced the highest shoot number at 4 and 6 MAP (Table 4.11).

Table 4.11 Effects of irrigation methods on shoot number in SCL soil.

Treatment	Shoot number (No./rai)		
	2 MAP	4 MAP	6 MAP
T1: Control	20,913^{c}	17,951	12,494
T2: Drip irrigation + WB model + Soil fertilizer	24,198^{ab}	20,395	13,704
T3: Drip irrigation + WB model + Fertigation	22,197^{bc}	21,161	15,309
T4: Drip irrigation + sensor + Fertigation	26,050^{a}	21,531	15,654
F-test	*	ns	ns
CV (%)	5.67	8.85	8.26

[1] Means in the same columns with different letters are significant differences based on DMRT at P < 0.05.

In LS soil, the shoot number in drip irrigation treatments (T2-T4) was also significantly higher than those in control (T1) at 2 and 4 MAP. Among irrigation treatments, T2 produce the highest shoot number at 4 MAP while T4 tended to produce the highest shoot number at 6 MAP (Table 4.12).

Table 4.12 Effects of irrigation methods on shoot number in LS soil.

Treatment	Shoot number (No./rai)		
	2 MAP	4 MAP	6 MAP
T1: Control	12,426^{c}	18,941^{c}	12,103
T2: Drip irrigation + WB model + Soil fertilizer	24,897^{a}	25,824^{a}	12,956
T3: Drip irrigation + WB model + Fertigation	19,529^{ab}	24,647^{b}	12,603
T4: Drip irrigation + sensor + Fertigation	18,985^{b}	24,235^{b}	13,103
F-test	**	**	ns
CV (%)	18.2	3.95	7.09

[1] Means in the same columns with different letters are significant differences based on DMRT at P < 0.05.

4.3.4. SCMR

In SCL soil, it was found that the SCMR in all treatments was not significantly different at 4 MAP. T4 tended to produce the highest SCMR (44.7) at 4 MAP. While at 6 MAP, the highest SCMR was obtained from T4 (40.3) compared to T2 (39.8), T3 (39.5), and T1 (32.3) (Table 4.13).

Table 4.13 Effects of irrigation methods on SCMR in SCL soil.

Treatment	SCMR (SPAD unit)	
	4 MAP	6 MAP
T1: Control	40.7	32.3[b]
T2: Drip irrigation + WB model + Soil fertilizer	40.9	39.8[a]
T3: Drip irrigation + WB model + Fertigation	42.4	39.5[a]
T4: Drip irrigation + sensor + Fertigation	44.7	40.3[a]
F-test	ns	**
CV (%)	3.96	2.00

[1] Means in the same columns with different letters are significant differences based on DMRT at P < 0.05.

In LS soil, it was found that the SCMR of all treatments was not significantly different at all MAP. However, T4 tended to produce the highest SCMR at 4 MAP (41.9) while T2 tended to produce the highest SCMR at 6 MAP (Table 4.14).

Table 4.14 Effects of irrigation methods on SCMR in LS soil.

Treatment	SCMR (SPAD unit)	
	4 MAP	6 MAP
T1: Control	40.1	39.6
T2: Drip irrigation + WB model + Soil fertilizer	41.4	41.9
T3: Drip irrigation + WB model + Fertigation	41.4	39.9
T4: Drip irrigation + sensor + Fertigation	41.9	40.4
F-test	ns	ns
CV (%)	5.03	4.75

[1] Means in the same columns with different letters are significant differences based on DMRT at P < 0.05.

4.3.5 Plant nutrients of the leaf

The leaf nutrient analysis showed that leaf N, P, K, Ca, and Mg were not significantly different between treatments. However, irrigation treatments (T2-T4) tended to have higher leaf nutrients than those in the rainfed treatment (T1).

The comparison of the leaf analysis to the standard nutrient content found that N and P in all treatments were lower than the standard nutrient content, K content was comparable to the standard value and Mg content was higher compared to the standard value. For Ca content, T4 was comparable but T1-T3 was lower than the standard value in SCL soil (Table 4.15).

Table 4.15 Effects of irrigation methods on plant nutrients of leaf in SCL soil at 4 MAP.

Treatment	Plant nutrient of leaf				
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
T1: Control	1.04	0.16	1.24	0.19	0.48
T2: Drip irrigation + WB model + Soil fertilizer	1.14	0.17	1.31	0.20	0.52
T3: Drip irrigation + WB model + Fertigation	1.09	0.17	1.26	0.21	0.51
T4: Drip irrigation + sensor + Fertigation	1.20	0.18	1.41	0.27	0.53
F-test	ns	ns	ns	ns	ns
CV (%)	9.85	21.0	13.2	13.2	11.1
Suitable nutrient content in sugarcane leaves	2.00-2.60	0.22-0.30	1.00-1.60	0.22-0.45	0.15-0.32

[1] Means in the same columns with different letters are significant differences based on DMRT at P < 0.05.

In LS soil, the leaf calcium was significantly different, but N, P, K, and Mg were not significantly different between treatments. The irrigation treatments (T2-T4) had higher Ca (1.16, 1.10, and 1.10%, respectively) than the rainfed treatment (T1). N, P, and K content in irrigation treatments (T2-T4) tended to be higher than in the rainfed treatment.

In the comparison of the leaf analysis and the standard nutrient content, it was found that N and P in all treatments were lower than the standard nutrient content and K content was comparable to the standard value. Ca and Mg content was higher compared to the standard value (Table 4.16).

Table 4.16 Effects of irrigation methods on plant nutrients of leaf in LS soil at 4 MAP.

Treatment	Plant nutrient of leaf				
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
T1: Control	1.33	0.14	1.14	0.75^{b}	0.29
T2: Drip irrigation + WB model + Soil fertilizer	1.41	0.15	1.28	1.16^{a}	0.28
T3: Drip irrigation + WB model + Fertigation	1.40	0.17	1.48	1.10^{a}	0.35
T4: Drip irrigation + sensor + Fertigation	1.41	0.18	1.46	1.10^{a}	0.36
F-test	ns	ns	ns	*	ns
CV (%)	5.52	13.4	11.3	10.1	21.9
Suitable nutrient content in sugarcane leaves	2.00-2.60	0.22-0.30	1.00-1.60	0.22-0.45	0.15-0.32

[1] Means in the same columns with different letters are significant differences based on DMRT at P < 0.05.

4.3.6 Yield and yield components

In SCL soil, the treatments significantly affected cane yield, stalk length, NMC and TSS. T4 produced the highest cane yield (19.0 tons/rai), stalk length (262 cm), NMC (14,889 stalks/rai), and TSS (24.6 ^{o}Brix), while the lowest cane yield (12.2 tons/rai), stalk length (192 cm), NMC (11,432 stalks/rai), and TSS (23.5 ^{o}Brix) were recorded in T1. The stalk diameter and stalk weight were not significantly different among treatments, but drip irrigation treatments (T2-T4) tended to produce higher than those in rainfed treatment (T1) (Table 4.17).

Table 4.17 Effects of irrigation on cane yield in SCL soil.

Treatment	Cane yield (tons/rai)	Stalk length (cm)	Stalk diameter (cm)	Stalk weight (kg/stalk)	NMC (stalk/rai)	TSS (^{o}Brix)
T1	12.2^{c}	192^{b}	2.93	1.06	11,432^{c}	23.5^{b}
T2	16.3^{b}	240^{a}	3.00	1.30	12,914^{bc}	24.0^{ab}
T3	17.6^{ab}	245^{a}	2.96	1.27	13,827^{ab}	24.6^{a}
T4	19.0^{a}	262^{a}	2.96	1.28	14,889^{a}	24.1^{ab}
F-test	**	**	ns	ns	**	*
CV (%)	5.61	4.58	6.03	11.8	6.09	1.35

T1 = Control, T2 = Drip irrigation + water balance model + Soil fertilizer, T3 = Drip irrigation + water balance model + Fertigation, T4 = Drip irrigation + sensor + Fertigation

[1] Means in the same columns with different letters are significant differences based on DMRT at P < 0.05.

In LS soil, T4 produced the highest cane yield (21.3 ton/rai), stalk length (323 cm), NMC (12,792 stalks/rai), and TSS (21.8 °Brix), while T1 had the lowest all of those yield and yield components. The stalk diameter and stalk weight were not significantly different among treatments, but drip irrigation treatments (T2-T4) tended to produce higher than those in rainfed treatment (T1) (Table 4.18).

Table 4.18 Effects of irrigation on cane yield in LS soil.

Treatment	Cane yield (tons/rai)	Stalk length (cm)	Stalk diameter (cm)	Stalk weight (kg/stalk)	NMC (stalk /rai)	TSS (°Brix)
T1	16.9^{b}	272^{b}	2.72	1.51	11,719^{b}	19.8^{b}
T2	20.8^{ab}	314^{a}	2.76	1.69	12,644^{ab}	20.8^{ab}
T3	20.6^{ab}	284^{ab}	2.92	1.70	12,656^{ab}	21.4^{ab}
T4	21.3^{a}	323^{a}	2.84	1.70	12,792^{a}	21.8^{a}
F-test	*	*	ns	ns	*	*
CV (%)	10.1	6.00	4.72	9.96	4.73	3.72

T1 = Control, T2 = Drip irrigation + water balance model + Soil fertilizer, T3 = Drip irrigation + water balance model + Fertigation, T4 = Drip irrigation + sensor + Fertigation

[1] Means in the same columns with different letters are significant differences based on DMRT at $P < 0.05$.

4.3.7 Irrigation water and fertilizer use efficiency

In SCL soil, it was found that all irrigation treatments had significantly different irrigation water use efficiency (IWUE). T4 had the highest (23.7 kg/mm/rai) and was different from other irrigation treatments (T2 and T3). For fertilizer use efficiency (FUE) analysis, it was found that all irrigation treatments (T2-T4) had significantly higher N, P, and K FUE than T1. T4 produced the higher FUE of N (0.91 tons/kg), P (1.19 tons/kg), and K content (1.27 tons/kg) than T1 N (0.58 tons/kg), P (0.76 tons/kg), and K content (0.81 tons/kg) (Table 4.19).

Table 4.19 Effects of irrigation methods on irrigation water and fertilizer use efficiency in SCL soil.

Treatment	IWUE (kg/mm/rai)	FUE (tons/kg)		
		N	P_2O_5	K_2O
T1: Control	-	0.58[b]	0.76[b]	0.81[b]
T2: Drip irrigation + WB model + Soil fertilizer	17.2[b]	0.89[a]	1.17[a]	1.25[a]
T3: Drip irrigation + WB model + Fertigation	18.6[b]	0.84[ab]	1.10[ab]	1.17[ab]
T4: Drip irrigation + sensor + Fertigation	23.7[a]	0.91[a]	1.19[a]	1.27[a]
F-test	*	*	*	*
CV (%)	14.0	17.6	17.7	17.8

IWUE=Irrigation water use efficiency, FUE=Fertilizer use efficiency

[1] Means in the same columns with different letters are significant differences based on DMRT at $P < 0.05$.

In LS soil (Table 4.20), it was found IWUE was not significantly different among irrigation treatments. However, T4 tended to produce the highest IWUE (18.2 kg/mm/rai) compared to T3 and T2. For FUE, it was found that all treatments had significantly different N and P FUE. T4 produced the higher N FUE (1.04 tons/kg) and P FUE (1.43 tons/kg) than T1 N FUE (0.81 tons/kg) and P FUE (1.11 tons/kg). K FUE in all treatments was not significantly different but T4 tended to produce the highest K FUE (0.65 tons/kg) in this soil.

Table 4.20 Effects of irrigation methods on irrigation water and fertilizer use efficiency in LS soil.

Treatment	IWUE (kg/mm/rai)	FUE (tons/kg)		
		N	P_2O_5	K_2O
T1: Control	-	0.81[b]	1.11[b]	0.51
T2: Drip irrigation + WB model + Soil fertilizer	16.5	0.97[ab]	1.33[ab]	0.61
T3: Drip irrigation + WB model + Fertigation	16.4	0.93[ab]	1.28[ab]	0.58
T4: Drip irrigation + sensor + Fertigation	18.2	1.04[a]	1.43[a]	0.65
F-test	ns	*	*	ns
CV (%)	14.2	14.7	14.8	15.2

[1] Means in the same columns with different letters are significant differences based on DMRT at $P < 0.05$.

The water requirement of sugarcane was in the range of 1,100–2,500 mm/season (Carr & Knox, 2011; FAO, 2011), and the highest daily ETc rates of 6.07 mm d−1 calculated based on the Penman-Monteith equation (Wonprasaid et al. 2021). The study of Paisancharoen et al. (2012) found that in each year the weather conditions were different. Therefore, sugarcane had different water requirements i.e. sugarcane had a water requirement of 1,591-1,620 mm in 2009/10 and 1,566-1,654 mm in 2010/11. In the irrigation controlled by water balance, the total water requirement of 1,224 and 1,276 mm from planting to harvesting in SCL soil and LS soil was calculated from crop evapotranspiration (ETc). The drip irrigation system controlled by the sensor (T4) provided 548 and 640 mm of irrigation water in SCL and LS soils, respectively, less than the drip irrigation controlled by the water balance model (T2-T3) which provided 694 and 729 mm of irrigation water in SCL and LS soils. Irrigation controlled by sensor (T4), although less irrigation water was applied, sugarcane still had sufficient water to maintain high growth and yield, thus resulted to more water saving than other irrigation methods.

The irrigating patterns, the number of irrigation supplies, and amount of irrigation water were different among treatments. The irrigation treatments (T2-T4) had more water supply than no irrigation treatment (T1). Between the irrigation treatments, the drip irrigation controlled by the water balance model (T3) which was a calculation based on historic weather conditions resulted to more water supply than the drip irrigation system controlled by the sensor (T4) ie. a real-time moisture measurement from the watermark sensor. Theoretically, irrigation based on the current soil moisture monitored by sensor should be more accurate than irrigation controlled by the water balance model as a result of non-uniformity of weather conditions. Currently, various types of humidity sensors were used and has been applied to control watering in various plants such as sugarcane (Wonprasaid et al. 2021) ; (Alamilla et al. 2016), cassava (Xie et al. 2020), barley (Jabro et al. 2020), and tomato (De Oliveira et al. 2021).

For the yield and yield component production, the drip irrigation treatments (T2-T4) which had high growth in the early growth stage (2, 4, and 6 MAP) influenced to higher yield production than the rainfed treatment which had lower growth. The rainfed condition had a high risk of water stress resulting in lower growth and productivity than the drip irrigation treatments. The drip irrigation system controlled by the sensor (T4) had a little higher growth and yield than the drip irrigation controlled by the water balance model (T2-T3) probably due to the more accuracy in water application. The drip irrigation system controlled by the sensor (T4) produced the highest yield of 19.0 and 21.3 tons/rai in SCL and LS soils, respectively. While the drip irrigation controlled by the water balance model (T2-T3) produced 16.3-17.6 and 20.6-20.8 tons/rai of sugarcane yield in SCL and LS soils, respectively, and the rainfed treatment had the lowest yields of 12.2 and 16.9 tons/rai in SCL and LS soils, respectively. The results were similar to Zafar et al. (2020) who reported that the sensor-based drip irrigation system (SD) produced higher yield 13.9-30.5 % and could save more water compared to conventional irrigation.

The drip irrigation system controlled by the sensor (T4) had higher IWUE than the drip irrigation controlled by the water balance model (T2-T3). Since T4 was a real-time moisture measurement, it provides accurate amount of water to meet crop water demand and no excess of water resulting in greater irrigation efficiency than irrigation based on calculated from historical weather conditions (T2 and T3). A study by Wonprasaid et al. (2021), who studied the effects of drip irrigation in sugarcane and found that drip irrigation control by sensor increased IWUE higher than traditional irrigation (water balance models), due to it tended to have a higher yield production and saved more water by 6.9%. A study on cassava by Xie et al. (2020) also found similar results that using sensors to control irrigation saved water by 10-80% compared to irrigation based on the water balance model.

In the comparison of FUE, the result showed that the fertigation had higher FUE than soil fertilizer application due to the fact that the fertilizer in the soluble form of fertilizer in fertigation was readily available and immediately absorbed by plant roots. On the other hand, the granule (solid) fertilizer which was applied in the soil application treatment was not readily available to plant and some fertilizer could be easily loss from the unsuitable conditions. The study by Pawar et al. (2013) who compared the effects of 2 fertilizer applications (soil fertilizer and fertigation), found that 100% drip fertigation had maximum yield and increased FUE by more than 40 % compared with soil fertilizer application. Moreover, it was found that soluble fertilizer in fertigation enhanced FUE by reducing the risk of water and fertilizer loss by 25–30% (Raina et al., 2011).