CHAPTER III
MATERIALS AND METHODS

3.1 Research Methodology

A series of 3 experiments were conducted during 2018 – 2020. The 1st experiment aimed to study the effect of drip irrigation controlled by the water balance model on growth, yield, and yield components in sugarcane. While the 2nd experiment was conducted under greenhouse conditions, it aimed to study the physiological process of sugarcane in the water deficit condition and well–irrigated conditions and the 3rd experiment aimed to compare the effect of drip irrigation controlled by a water balance model and a wireless sensor system on growth and yield of sugarcane.

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

3.2.1 Experimental design

The experimental design was a randomized complete block design (RCBD) with 3 treatments and 3 replications. Sugarcane CV. Khon Kaen 3 (KK3) was planted in SL soil at KI sugarcane field, Buachet, Surin, Thailand (14°31'19.0"N 103°54'27.2"E).

Sugarcane CV. KK3 is a popular cultivar in the Northeast. It is a hybrid between clones 85-2-356 and K 84-200. The average cane yield is 12-22 tons/rai. It is fast growing with high ratooning ability. The recommended planting area is flat or upland with good drainage. It is suitable for planting in sandy loam soil (Office of Cane and Sugar Board, n.d.).

The treatments were as follows:

T1: Control (rainfed practice)

T2: Half water supply based on the water balance model

T3: Full water supply based on the water balance model

3.2.2 Materials and Method

1) Soil preparation and planting

The soil was prepared by deep plowing and turning over to control weeds. About a week after deep plowing, the soil was rotary plowed. The sugarcane was planted with the growing machine at the distance between double rows of 1.6 m. The plot size of each treatment was 70x33.6 m.

2) Soil properties before the experiment

The soil was analyzed for soil fertility, which was used to determine the fertilizer formula. The acidity–alkalinity (pH) was measured using soil: water (1:1) by pH meter. The electrical conductivity (EC) was measured using soil: water (1:5) by EC Meter. Organic matter (OM) content was analyzed by Walkley and Black method (Walkley, 1945). Available phosphorus was analyzed by the Bray II method (Bray & Kurtz, 1945) and measured by Spectrophotometer. The soil was extracted with 1.0 M of NH_4OAC and exchangeable K, Ca and Mg were measured by Atomic Absorption Spectrophotometer (AAS) (David,1960). The results of soil analysis at the depth of 0–40 cm are shown in Table 3.1. It was found that the soil texture was sandy loam.

Table 3.1 Soil properties before the experiment on CV. KK3.

Sample (dept.)	pH 1:1	EC (dS/m)	OM (%)	Av.P (mg/kg)	Ex.K (mg/kg)	Ex.Ca (mg/kg)
0–40 cm.	4.89	0.138	0.45	17.3	43.3	283

OM: organic matter; Av.P: available P; Ex.K: exchangeable K; Ex.Ca: exchangeable Ca

3) Irrigation management and fertilizer application

3.1) Irrigation management

For all treatments, the water was irrigated to the sugarcane by drip irrigation systems. The drip tapes with the distance among the drip hole of 30 cm and the flow rate of 2 liters/hour were installed at planting. Water was irrigated based on the water balance model equation (1) (Pereira et al., 2020)

$$I=ET+DR+RO+\Delta W-P \qquad (1)$$

When I is the irrigation

ETc is the evapotranspiration

DR is drainage

RO is the surface runoff

ΔW is the AWHC

P is the precipitation

The treatment was irrigated as follows:

– In T1, water was irrigated 2– 3 times to maintain the sugarcane germination until 30 days after planting (DAP).

– In T3, water supply was determined from the water balance model using crop water requirement (ETc) and soil water holding capacity (SWHC). The crop water requirement was calculated from historical weather data in the area and crop coefficient (Kc). The amount of water supply each time was based on the field capacity (FC) of the soil. In the 1–2 months after planting (MAP), the available water holding capacity (AWHC) was calculated at a depth of 0–20 cm after 2 MAP, it was calculated at a depth of 0–40 cm The irrigation was supplied when 60 percent of available water was used by sugarcane. If there was rainfall between the irrigation periods, the irrigation was canceled or delayed according to the amount of rainfall (Table 3.2).

– In T2, the water was supplied at the same frequency as full water supply, but the amount of water supply was equal to half amount of water supply in T3.

Table 3.2 The amount of water requirement for sugarcane from January to December 2018 at Bua Chet Farm.

Months	Number of days	ETp (mm/day)	Kc	ETc (mm/day)	ETc (mm/months)	Rainfall (mm)
Jan	31	3.66	0.47	1.72	53.3	5.00
Feb	28	4.31	0.68	2.93	87.9	0
Mar	31	4.89	0.85	4.16	129	90.0
Apr	30	5.10	1.03	5.25	158	45.0
May	31	4.87	1.20	5.84	181	155
Jun	30	4.35	1.00	4.35	135	28.0
Jul	31	4.25	0.86	3.66	110	165
Aug	31	4.08	0.65	2.65	82.2	156
Sep	30	3.79	0.50	1.90	56.9	–
Oct	31	3.84	0.42	1.61	50.0	–
Nov	30	3.71	–	–	–	–
Dec	31	3.53	–	–	–	–
Total (mm)		50.4	7.66	34.07	1,043	644

3.2 Fertilizer application

The fertilizer rates of the nutrient balance model were calculated based on the nutrient balance equation (2) as the same study of Wonprasaid et al. (2021)

$$NS = \frac{NR-(SAN-SM)}{NUE} \qquad (2)$$

Where NS is the nutrient supply (kg/rai)

NR is the nutrient required for the target yield of 20-25 tons/rai

SAN is the amount of soil available nutrients that obtain from soil analysis (kg/rai) in Table 3.3 and 3.7

SM is the minimum amount of soil nutrient (OM=1%, P=10mg/kg and K=60mg/kg for SCL; OM=0.5%, P=5mg/kg and K=30mg/kg for LS and SL)

NUE is nutrient use efficiency for soil uptake (N=80%, P=60% and K=80%) for both soils

The fertilizer rate was based on soil analysis as follows:

– In T1 and T2, fertilizer application was soil applications, urea (46–0–0) was used as the source of N fertilizer, diammonium phosphate (18–46–0) was used as the source of P, and potassium chloride (0–0–60) was used as the K source. The soil fertilizer application was applied 2 times at 1 and 3 MAP in Table 3.3.

– In T3, fertilizers were applied by fertigation using Urea (46–0–0) as the source of N fertilizer, and Monoammonium phosphate (12–61–0) as the source of P, and potassium chloride (0–0–60) as K source. The fertigation was applied every 7–10 days for 7 times from 1 MAP (applied) in Table 3.3. The fertilizers were applied as the same formulas as T1 and T2, but the source of fertilizers was different.

Table 3.3 Rate of fertilizer recommended based on nutrient balance model in SL soil.

Soil texture	N (kg/rai)	P_2O_5 (kg/rai)	K_2O (kg/rai)
SL	22	12	35

3.2.3 Data collection

1) Sugarcane growth parameters

Sugarcane growth parameters were collected at the 2, 4, and 6 MAP in the area of 4.8 x 4 m (19.2 m^2) from recommended double rows (Hassan et al., 2017).

– The plant height was measured from the ground to the top visible dewlap (TVD).

– The shoot number was counted.

– The SPAD chlorophyll meter reading (SCMR) was measured on the 3rd fully expanded leaf from the top of the main stem of each plant at the 4 MAP.

– The plant nutrient of leaf on the 3rd leaf was analyzed at 4 MAP, including N, P, K and Ca.

2) Yield and yield components

The yield and yield components were collected in the area of 4.8 x 4 m (19.2 m^2). The data were collected as follows:

– The stalk length (cm) was measured from the base of the plant to the TVD from 10 stalk samples.

– The stalk diameter (middle of stalk) was measured using a vernier caliper from 10 plant samples.

– The stalk weight (kg/stalk) was randomly measured from 10 plant samples.

– The number of millable cane (NMC) was calculated from recommended area.

– The yield was evaluated in the sampling area and converted into tons/rai.

3.2.4 Statistical analysis

The data of plant growth, yield, and yield components were analyzed using the Statistical Package for the Social Science (SPSS) version 16.0, and the mean comparisons were compared by the Duncan's New Multiple Range Test (DMRT) at P=0.05.

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

3.3.1 Experimental design

The experiment was conducted in greenhouse conditions at Suranaree University of Technology farm, Muang, Nakhon Ratchasima, Thailand (14°52'38.4"N 102°00'23.0"E). The experimental design was a RCBD with 3 treatments and 3 replications.

The treatments were as follows:

T1: Irrigation (Control)

T2: Water deficit condition at 3 months

T3: Water deficit condition at 7 months

3.3.2 Materials and Method

1) Soil preparation and planting

Sugarcane CV. KK3 was grown in 150–liter pots filled with sandy clay loam soil.

2) Irrigation management

For all treatments, water was supplied to the sugarcane using a drip irrigation system with a flow rate of 8 liters/hour. Irrigation in each treatment was performed as follows:

– In T1, the water supply pattern (frequency and amount) was determined from the water balance model using ETc and SWHC. The ETc was calculated from historical weather conditions in each area and Kc. The number of water supplies each time was based on the FC of the soil. In the 1–2 MAP, the AWHC was calculated at a depth of 0–20 cm. after 2 MAP, it was calculated at a depth of 0–40 cm. The irrigation was supplied when 60 percent of available water was used by sugarcane.

– In T2, the water was supplied as same as T1 until at 3 MAP, after that, no water was irrigated for 14 day to create the water deficit conditions. Then the water was irrigated again until harvesting.

– In T3, the water was supplied as same as T1 until at 7 MAP, after that, no water was irrigated for 16 day to create the water deficit conditions. Then the water was irrigated again until the harvesting.

3.3.3 Data collection

1) Growth parameter

Growth parameter was collected at 3 and 7 MAP.

– The plant height was measured randomly from the soil base to the TVD.

– The shoot number was counted in the pot plant of all treatments.

– The number of leaves was counted in the pot plant of all treatments.

2) Physiological process

– The SCMR was measured on the 3rd leaf using a Chlorophyll Meter (SPAD) at the 3 and 7 MAP.

– The leaf water potential (the 3rd leaf) was measured from 10.00–14.00 hrs (Jaiphong et al., 2017) using a photosynthesis LCi–SD model at 3 and 7 MAP.

– The photosynthetic rate, transpiration rate, and stomatal conductance (the 3rd leaf) were measured from 10.00–14.00 hrs (Jaiphong et al., 2017) using a photosynthesis LCi–SD model at 3 and 7 MAP.

3) Yield and yield components

– The stalk length (cm) was measured from the base of the plant to the TVD in the pot plant of all treatments.

– The stalk diameter (middle of stalk) was measured on the main stalk using a vernier caliper in the pot plant of all treatments.

– The stalk weight (kg) was recorded from the stalk per pot of all treatments.

– The stalk number (stalk/pot) was counted in the stalk per pot plant of all treatments.

– The yield (kg) was recorded from stalk per pot of all treatments.

– The total soluble solid (TSS) (°Brix) was analyzed using reflectometer.

3.3.4 Statistical analysis

The data of growth parameters, physiological process, yield, and yield components were analyzed using the SPSS version 16.0. The mean was compared by the DMRT at P=0.05.

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

3.4.1 Experimental design

The experimental design was a RCBD with 4 treatments and 3 replications. The experiment was conducted on sugarcane CV. KK3, and it was grown in 2 soil textures.

– The Sandy clay loam soil (SCL) was conducted at Suranaree University of Technology farm, Muang, Nakhon Ratchasima, Thailand at the position of 14°52'38.4"N 102°00'23.0"E.

– The Loamy sand soil (LS) was conducted at KI sugarcane field, Buachet, Surin, Thailand, at the position of 14°30'45.0"N 103°54'19.4"E.

In both soils, the treatments were:

T1: Control (no irrigation) + Soil fertilizer application

T2: Drip irrigation controlled by water balance model + Soil fertilizer

T3: Drip irrigation controlled by water balance model + Fertigation

T4: Drip irrigation system controlled by sensor + Fertigation

3.4.2 Materials and Method

1) Soil preparation and planting

Soil preparation and planting were the same as in experiment 1.

2) Soil properties before the experiment in SCL and LS soil

Soil properties before the experiment at a depth of 0–40 cm were analyzed as the same procedure as experiment 1.

The soil at Suranaree University of Technology farm was classified as SCL soil and at KI sugarcane field was classified as LS soil. Soil's chemical and physical properties are shown in Table 3.4.

Table 3.4 Soil properties before the experiment in SCL and LS soil.

Soil properties	SCL soil	LS soil
Chemical properties		
EC (dS/m)	0.070	0.027
pH (1:5)	7.46	5.70
OM (%)	1.25	0.93
Av.P (mg/kg)	8.86	5.03
Ex.K (mg/kg)	76.8	43.7
Ex.Ca (mg/kg)	2,327	650
Ex.Mg (mg/kg)	171	124
Physical properties		
Sand (%)	46.2	81.5
Silt (%)	22.5	9.20
Clay (%)	32.3	9.30
Bulk density (g/cm^3)	1.25	1.35
FC (%v)	36.8	17.9
PWP (%v)	20.3	6.90
AWHC (mm/cm)	1.65	1.10
Texture	Sandy clay loam	Loamy sand

EC: Electrical conductivity; OM: Organic matter; P: Available P; K: Exchangeable K; Ca: Exchangeable Ca; Mg: Exchangeable Mg; AWHC: available water holding capacity; SCL: Sandy clay loam; LS: Loamy sand

3) Irrigation and fertilizer application

3.1) Irrigation

For all treatments, the water was irrigated to the sugarcane using a drip irrigation system (drip tape) which was installed after planting. The distance among the drip hole was 30 cm and the flow rate was 2 liters/hour. The treatment was irrigated as follows:

– T1 was irrigated only 2–3 times after planting until 30 DAP for uniform germination of sugarcane.

– In T2 and T3, the water supply pattern (frequency and amount) was determined from the water balance model using ETc and SWHC in Tables 3.5 and 3.6. The crop water requirement was calculated from historical weather conditions in each

area and Kc. The amount of water supply each time was based on the FC of the soil. In the 1–2 MAP, the AWHC was calculated at a depth of 0–20 cm, after 2 MAP, it was calculated at a depth of 0–40 cm. The irrigation was supplied when 60 percent of available water was used by sugarcane. If there was rainfall between the irrigation periods, the irrigation was canceled or delayed according to the amount of rainfall.

– In T4, the soil moisture sensor (watermark) was installed at the soil depth of 20 and 40 cm to monitor soil water potential. When the soil water potential was higher than -80 centibar, water was supplied. At 1–2 MAP, only the soil moisture values of the upper sensor were used, but after 2 MAP the average values of both sensors were used. The amount of water supply each time was based on the FC of the soil.

Table 3.5 The amount of water requirement of sugarcane from February 2019 to January 2020 in SCL soil.

Months	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Total (mm)
Number of days	28	31	30	31	30	31	31	30	30	30	–	–	
ETp	3.95	4.39	4.64	4.20	3.95	3.89	3.79	3.36	3.42	3.51	3.41	3.37	
Kc	0.65	0.86	1.13	1.35	1.56	1.29	1.20	0.93	0.63	0.52	–	–	10.1
ETc (mm/day)	2.57	3.78	5.24	5.67	6.16	5.02	4.55	3.12	2.15	1.83	–	–	4.01
ETc (mm/months)	35.9	117	157	176	185	156	141	93.7	64.6	54.8	–	–	1181

Table 3.6 The amount of water requirement of sugarcane from December 2018 to November 2019 in LS soil.

Months	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total (mm)
Number of days	31	31	28	31	30	31	30	31	31	30	–	–	
ETp	3.65	3.85	4.96	5.22	5.39	4.83	4.56	4.36	4.04	4.13	4.06	3.97	
Kc	0.65	0.86	1.13	1.35	1.56	1.29	1.20	0.93	0.63	0.52	–	–	10.1
ETc (mm/day)	2.37	3.31	5.60	7.05	8.41	6.23	5.47	4.05	2.55	2.15	–	–	4.72
ETc (mm/months)	73.5	103	157	219	252	193	164	126	78.9	64.4	–	–	1431

3.2) Fertilizer application

The fertilizer rate was based on soil analysis and fertilizer methods were as follows:

– Fertilization in T1 and T2 were soil fertilizer applications in which fertilizers were applied 2 times at 1 and 3 MAP using N (46–0–0), P (18–46–0), and K (0–0–60) in Table 3.7.

– T3 and T4 were fertigations using N (46–0–0), P (12–61–0), and K (0–0–60). For the fertigation, fertilizers were equally applied 7 times from 1 MAP (applied every 7–10 days) in Table 3.7. The fertilizers were applied as the same formulas as T1 and T2, but the sources of fertilizer were different.

Table 3.7 Rate of fertilizer recommended based on nutrient balance model in SCL and LS soil.

Soil texture	N (kg/rai)	P_2O_5 (kg/rai)	K_2O (kg/rai)
SCL	21	16	15
LS	22	16	35

3.4.3 Data collection

1) Rainfall, water requirement, and water supply

Rainfall, water requirement, and water supply were recorded in each treatment throughout the growing season.

Soil water potential was measured at 09:00 am using soil moisture sensors (Watermark), that were installed in the field at 2 soil depths (20 cm and 40 cm).

2) Sugarcane growth

Plant growth was collected at the 2, 4, and 6 MAP in the area of 4.8 x 4 m (19.2 m^2) from recommended double rows.

– The plant height was measured randomly from the soil base to the TVD.

– The shot number was counted.

– The SCMR was measured at the 3rd leaf using a SPAD Meter at the 4 and 6 MAP.

– The nutrient of leaves at the 3rd leaf was analyzed at the 4 MAP, including N, P, K, Ca, and Mg.

3) Yield and yield components

The yield and yield components were collected in the area of 4.8 x 4 m (19.2 m^2), the data were collected as follows:

– The stalk length (cm) was measured from the base of the plant to the TVD from 10 plant samples.

– The diameter (middle of stalk) was measured by using a vernier caliper from 10 plant samples.

– The stalk weight (kg/stalk) was measured from 10 plant samples.

– The NMC was calculated from recommended area.

– The yield was evaluated in the sampling area and converted into tons/rai

– The sugarcane TSS (°Brix) was analyzed using reflectometer.

4) Irrigation Water and Fertilizer use efficiency

Irrigation water use efficiency (IWUE) and Fertilizer use efficiency (FUE) were calculated during the harvesting (Xie et al., 2018) and estimated as follows:

$$IWUE = \frac{\text{yield (kg/rai)}}{\text{amount of water supply } (m^3/\text{rai})}$$

$$FUE = \frac{\text{yield (kg/rai)}}{\text{amount of fertilizer (kg/rai)}}$$

3.4.4 Statistical analysis

The data of plant growth, physiological data, yield, and yield components were analyzed using the SPSS version 16.0, and the mean was compared by the DMRT at P=0.05.