Effects of Fertigation and Water Application Frequency on Yield, Water and Fertilizer Use Efficiency of Chili (*Capsicum annuum* L.).

S. Chanthai, and S. Wonprasaid*

Abstract—Drip irrigation is becoming popular for chili production in dry season. However, there is no suitable recommendation on water and nutrient application for chili under drip irrigation system. This experiment was conducted with the objective of evaluating the effects of fertigation, water application frequency and soil amendment on chili yield, fertilizer and water use efficiency under drip irrigation system. The treatments included three water application frequencies (1. at cumulative crop evapotranspiration (ETc) = 15 mm, 2. ETc = 25 mm and 3. ETc = 35 mm); two fertilization methods (fertigation and solid fertilizer application); and two soil amendments (with and without soil amendment). The results revealed that fertigation produced higher chili yield and fertilizer use efficiency than solid fertilizer application regardless of water application frequency and soil amendment. Without soil amendment, most frequent water application (ETc 15 mm) resulted to the greatest yield and water use efficiency. With soil amendment, the impact of water application frequency on chili yield was small and all water application frequencies produced similar yield.

Index Terms—Chili, Drip irrigation, Fertigation, Water holding capacity, Plant water requirement.

I. INTRODUCTION

Chili is one of the important economic crops in Thailand. In 2013, the total growing area was about 24,000 ha [1]. It is grown during the dry season under irrigation system in the Northeast. The average yield in farmer fields is very low (5.81 t ha^{-1}) due to plant pests, low fertility soil and poor management practices. Drip irrigation as the most efficient irrigation method is recommended in this area. However, no information of proper water management such as the frequency and amount of water application is available.

High temperature and low humidity cause high crop evapotranspiration, therefore high amount of water has to be applied to meet the crop requirement. Since most of the soils in this area are sandy with low organic matter content and low water holding capacity (WHC), if water is applied more than the WHC of the soil, there will be water and nutrients loss due to leaching.

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S. Chanthai is a graduate student of Institute of Agricultural Technology, Suranaree University of Technology, Nakhon Ratchasima 30000, Thailand

S. Wonprasaid is with Institute of Agricultural Technology, Suranaree University of Technology, Nakhon Ratchasima 30000 Thailand

To prevent water and nutrient leaching, low amount of water (less than the WHC) has to be frequently applied.

To reduce the frequency of water application without any effect to the plant could be done by improve soil water holding capacity. Coir dust has been reported to improve soil water holding capacity, cation exchange capacity (CEC) and reduce bulk density of the soil [2] because it can absorb 8 times of water relative to its weight [3]. Incorporating coir dust at 2% of the soil weight was able to increase soil water holding capacity by 40% [4]. It has been successfully used as plant growth media for soilless culture. It could be adopted to use as soil amendment for the open crops such as chili if it is proved to be effective.

Besides water application, soil fertilizer application in this area is ineffective. Leaching is the main fertilizer loss as the soil is sandy with low water holding capacity. Fertigation with a suitable water application technique will help to improve both water and fertilizer use efficiency under this condition. There is limited information of water application and fertigation for chili in this area.

The objectives of this study were: 1) to determine the amount and the frequency of water application, 2) to study the effect of soil amendment (coir dust) on soil water holding capacity and its effect on water application frequency and 3) to compare the effects of fertigation and solid fertilizer application on fertilizer use efficiency, chili growth and yield.

II. MATERIAL AND METHODS

The field experiment was conducted in sandy loam soil of Chatturat soil series: Ct (Fine, mixed, active isohyperthermic Typic Haplustalfs), at Suranaree University of Technology, Nakhon Ratchasima, Thailand. The chemical and physical properties of experimental soil are shown in Table I. The available water holding capacity of the soil is 11.4 % of volumetric water content.

The experimental design was split plot in RCBD with 3 replications. The main plots were the combination treatments of 2 methods of fertilizer application (soil application and fertigation) and 3 water application frequencies (at cumulative crop evapotranspiration (ETc) 15, 25 and 35 mm). The sub plots were with and without soil amendments (coir dust). Coir dust (Table I) at the rate of 18.7 t ha^{-1} was incorporated at the same time of soil preparation. Soil was covered with black plastic sheet, and the inline drippers with 2 L h^{-1} of water discharge were installed under the plastic sheet. The plot size was 1 x 5 m. with a plant spacing of 0.5 x 0.5 m. After soil

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preparation, 30 days old chili seedlings cv. Super Hot was transplanted.

TABLE I
PROPERTIES OF EXPERIMENTAL SOIL (0-15 CM) AND COIR DUST

Properties	Soil	Coir dust
pH	7.81	6.01
EC (μS m^{-1})	113	1417
Organic matter (%)	1.28	59.6
Organic carbon (%)	0.74	34.7
N (%)	0.06	0.36
C:N	12.1	96.1
P (mg kg^{-1})	54.4	0.03(%)
K (mg kg^{-1})	74.0	1.89(%)
Field capacity (Vol%)	28.5	119
Permanent wilting point (Vol%)	17.1	30.6
Water holding capacity (Vol%)	11.4	88.3

The amount of water to be applied each time was equivalent to the cumulative ETc in each treatment (Table II). Therefore, the most frequent water application treatment (ETc 15 mm) received the least amount of water each time, while the least frequent water application (ETc 35 mm) received the largest amount of water. At the end of the experiment, all treatments received almost the same amount of water. The cumulative ETc 15-35 mm was used according to the soil available water holding capacity (11.4%). The ETc of chilis was calculated by the following equation:

$$ETc = ETp \times Kc \quad \text{........... [5]}$$

Where ETp is the potential evapotranspiration estimated based on the long-term average climatic data in this area [6]. Kc is the crop coefficient which is affected by several factors such as crop types, crop stages and cultural practices.

TABLE II
MONTHLY ETP, KC, ETC, AVERAGE WATER APPLICATION FREQUENCY AND AMOUNT OF WATER SUPPLY.

Data	January	February	March	April	May
ETp (mm/day)	3.86	5.11	5.25	5.61	5.10
Kc	0.67	0.67	0.67	0.67	0.67
ETc (mm/day)	2.59	3.42	3.52	3.76	3.42
Water application frequency (days)					
ETc 15 mm.	5	4	4	3	4
ETc 25 mm.	9	7	7	6	7
ETc 35 mm.	13	10	9	9	10
Water supply (mm/time)					
ETc 15 mm.	13.0	13.7	14.1	11.3	13.7
ETc 25 mm.	23.3	23.9	24.6	22.6	23.9
ETc 35 mm.	33.7	34.2	31.7	33.8	34.2
Total water supply (mm/month)					
ETc 15 mm.	80	96	109	112	106
ETc 25 mm.	80	96	109	112	106
ETc 35 mm.	80	96	109	112	106

Rate of fertilizer application based on soil test [7] was 105-25-75 kg N, P_2O_5, K_2O ha^{-1}. For solid fertilizer application, fertilizer was applied twice with a half rate at transplanting and the first flowering stage. For fertigation, fertilizer was applied weekly in equal amount from transplanting to the first flowering stage (10-12 times depending on water application frequency treatments). All treatments received the same amounts of N, P and K at the end of fertigation.

Plant height, leaf area index (LAI), and dry matter were recorded at the first flowering stage while yield and yield component were recorded at harvest. Fertilizer use efficiency (FUE) was determined as a factor of total economic yield from all harvests by quantity of nutrient applied. The amounts of applied water were recorded throughout the growing period. Water use efficiency (WUE) was also estimated by dividing total economic yield with amounts of water applied.

All data were subjected to analysis of variance (ANOVA) using SPSS v. 13 for Window [8]. Means were compared by Duncan's Multiple Rang Test (DMRT).

III. RESULTS AND DISCUSSION

1. Water Application

Table II shows the values of ETp, Kc and ETc and the frequency of water application. The maximum value of ETc (3.76 mm day^{-1}) was recorded in April which is the hottest and driest month in this area. The frequency of water application estimated from the cumulative ETc was found to be most frequent in April in all treatments. The average water application frequency of treatment ETc 15 mm ranged between 3-5 days while those of treatment ETc 35 mm ranged between 9-13 days. Total amounts of water application in all treatments were similar at about 500 mm.

2. Growth, Yield and Yield Components

In general, plant growth (plant height, LAI, dry matter and % light interception) responded to fertilization method, water application frequency and soil amendment (Table III). Fertigation produced taller plant, higher LAI, and dry matter than solid fertilizer application. The most frequent water application (ETc 15 mm) produced the greatest growth parameters while soil amendment improved all plant growth parameters recorded.

Fertigation also gave higher weight of 100 fruits and total yield than soil application (Table IV). Similar to plant growth, the most frequent water application (ETc 15 mm) gave the highest weight of 100 fruits (218 g) and total yield (13.58 t ha^{-1}), and coir dust incorporation produced greater weight of 100 fruits (215 g) and yield (10.37 t ha^{-1}) than the control.

There were no significant interactions among fertilization method and water application frequency and soil amendment on chili yield but a significant interaction existed between water application frequency and soil amendment (Fig. 1a). Without soil amendment water application frequency had a large effect on chili yield, while with soil amendment it had a little effect. This implied that soil amendment could reduce the water application frequency for chili production in the sandy loam soil.

TABLE III
PLANT HEIGHT, L EAF AREA INDEX (LAI) AND DRY MATTER OF CHILI.

Treatment	Plant height (cm)	LAI	Dry matter (g $plant^{-1}$)
Fertilizer application			
Fertigation	79.63	2.74	21.47
Solid application	77.83	2.63	19.38
Water application frequency			
ETc 15 mm	81.12	3.29a	24.51a
ETc 25 mm	78.52	2.58b	20.35b
ETc 35 mm	76.56	2.18c	16.41c
Soil amendment			
With	80.01	3.04a	22.56a
Without	77.45	2.33b	18.29b
% CV.	4.51	6.85	11.50

In a column within each factor, means followed by a common letter are not significantly different at 5 % level by DMRT

TABLE IV
YIELD AND YIELD COMPONENTS OF CHILI.

Treatment	Yield (t ha^{-1})	Weight of 100 fruits (g)	Rotten fruits (%)
Fertilizer application			
Fertigation	12.09a	206a	2.19b
Solid application	11.48b	182b	2.32a
Water application frequency			
ETc 15 mm	13.58a	218a	2.27ab
ETc 25 mm	12.92b	207b	2.18b
ETc 35 mm	8.87c	156c	2.33a
Soil amendment			
With	13.21a	215a	2.26
Without	10.37b	173b	2.26
% CV.	5.05	5.10	6.24

In a column within each factor, means followed by a common letter are not significantly different at 5 % level by DMRT

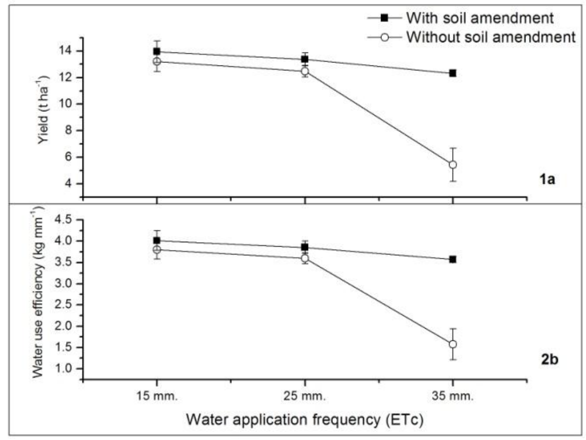

Fig. 1. Interaction between water application frequency and soil amendment on chili yield (a) and water use efficiency (b)

3. Water And Fertilizer Use Efficiency

As the amounts of applied water and fertilizer were the same in all treatments, the WUE and FUE responded exactly the same to fertilization, water application frequency and soil amendment as chili yield. The values of WUE ranged between 2.99 - 3.90 kg m^{-3} which was in the range of WUE reported by the other study with similar climatic conditions [9].

There were no significant interactions among fertilization method and water application frequency and soil amendment on WUE, but a significant interaction existed between water application frequency and soil amendment (Fig. 1b).

Since the FUE in this study was calculated as total economic yield divided by amount of applied fertilizer regardless of the soil nutrients, its values were higher than the values reported from the literatures [10], [11].

Effect of fertilizer application methods on FUE was associated to nutrient uptake. Since dry matter was also greater in the fertigation treatment, it can be implied that the nutrient uptake was greater under the fertigation method. The beneficial effects of fertigation over solid fertilizer application have been reported [12], [13]. Badr et al., 2010 [11] reported that N and K applied via fertigation were confined to the root zone, while they moved beyond the root zone when they were applied as solid fertilizer. They also reported that the mobility of P was greater in the root zone following its application through fertigation compared to a solid fertilizer application. They concluded that chili plants were able to utilize applied nutrients more efficiently in fertigation system than with solid fertilizer application. In this study, the downward nutrients movement was not examined. However, the more nutrient uptake by plants under the fertigation system implied that nutrients were more available at the root zone of chili plants during the growing period under the fertigation system.

TABLE V
WATER USE EFFICIENCY (WUE) AND FERTILIZER USE EFFICIENCY (FUE) OF CHILI.

Treatment	WUE ($kg.mm^{-1}$)	FUE ($kg\ kg^{-1}$)		
		N	P	K
Fertilizer application				
Fertigation	3.43a	3.36a	120a	13.4a
Solid application	3.31b	3.18b	114b	12.7b
Water application frequency				
ETc 15 mm	3.90a	3.77a	135a	15.0a
ETc 25 mm	3.72b	3.58b	129b	14.3b
ETc 35 mm	2.57c	2.46c	88.0c	9.85c
Soil amendment				
With	3.81a	3.66a	132a	14.6a
Without	2.99b	2.88b	103b	11.5b
% CV.	5.08	5.08	5.05	5.05

In a column within each factor, means followed by a common letter are not significantly different at 5 % level by DMRT

4. Soil Physical And Chemical Properties

The soil physical and chemical properties analyzed after the last harvesting were shown in Tables VI and VII. Soil permeability and available water holding capacity (AWHC) significantly increased, while soil bulk density decreased with the soil amendment compared to the control. Plant AWHC was defined as the difference between water content at field capacity and permanent wilting point. Fig. II shows the relationship between water extraction tension and soil water content. It can be seen that at all extraction tensions, the soil water contents were greater in the soil with coir dust incorporation than in the control. However, the differences of water content between the two treatments were greater at the tension level associated with the field capacity (9.8 kPa) than with the permanent wilting point (1569.6 kPa). This result led to the increase in AWHC of the soil with coir dust incorporation. The resulted was similar to the results reported by Thampan (1981) [4] who found that coir dust incorporation with 2 % of soil weight improved AWHC by 40%.

The interaction between water application frequency and soil amendment on yield and WUE (Fig.1a and 1b) was attributed to the improvement of AWHC by soil amendment. Without soil amendment, the available water holding capacity (AWHC) of the soil is low (11.4-11.6%) (Tables I and VI). In treatment of water application at 35 mm, water would percolate through to about 80 cm depth while water application at 15 mm, it would percolate through to 35 cm. Therefore, for treatment of ETc 35 mm. (the least frequent application of water, 9-13 days), some amount of applied water would move deeper than chili root zone and that would reduce the amount of available water for chilli. Moreover, the downward movement of water could leach some plant nutrients out of the root zone which led to low FUE and productivity of chili in this treatment. On the other hand, with soil amendment, AWHC increased to 17.4% (Table VI). Water application at 35 mm, water would percolate through to only 40 cm depth which was still inside the chili root zone. There were no water and fertilizer loss.

There were little effects of fertilizer application method and water application frequency on soil chemical properties and plant nutrients except for P (Table VII). Soil P was greater in the solid fertilizer application than in the fertigation treatment, suggesting that more P was removed by plants under the fertigation system. Since P mobility in the soil is normally limited, fertigation with solution P could facilitate its movement to the roots and enhance P uptake by the plants. This result is in agreement with the result of Badr et al., (2010) [11].

TABLE VI
SOIL PHYSICAL PROPERTIES AFTER HARVESTING.

Treatment	Permeability ($mm\ h^{-1}$)	Bulk density ($g\ cm^{-3}$)	AWHC (%)
Fertilizer application			
Fertigation	64.69	1.23	15.06
Solid application	61.69	1.18	13.93
Water application frequency			
ETc 15 mm	70.74	1.16	14.89
ETc 25 mm	70.57	1.26	14.46
ETc 35 mm	48.26	1.20	14.13
Soil amendment			
With	85.79a	0.97b	17.39a
Without	40.58b	1.44a	11.60b
% CV.	16.62	9.12	32.83

In a column within each factor, means followed by a common letter are not significantly different at 5 % level by DMRT

TABLE VII
SOIL CHEMICAL PROPERTIES AFTER HARVESTING.

Treatment	pH	EC ($\mu S\ m^{-1}$)	OM (%)	Available P ($mg\ kg^{-1}$)	Exchangeable K ($mg\ kg^{-1}$)	Exchangeable Ca ($mg\ kg^{-1}$)
Fertilizer application						
Fertigation	6.26a	55.06b	1.23	9.77b	57.57b	723.2b
Solid application	5.93b	68.04a	1.02	16.19a	71.84a	829.2a
Water application frequency						
ETc 15 mm	6.14	57.59	1.09	10.19b	60.73	733.4
ETc 25 mm	6.19	67.10	1.21	10.40b	69.44	777.1
ETc 35 mm	5.97	59.95	1.08	18.34a	63.94	818.1
Soil amendment						
With	6.00	62.91	1.55a	10.38b	74.26a	813.7a
Without	6.19	60.19	0.71b	15.58a	55.14b	738.2b
% CV.	4.3	22.38	40.75	33.74	41.17	9.11

In a column within each factor, means followed by a common letter are not significantly different at 5 % level by DMRT

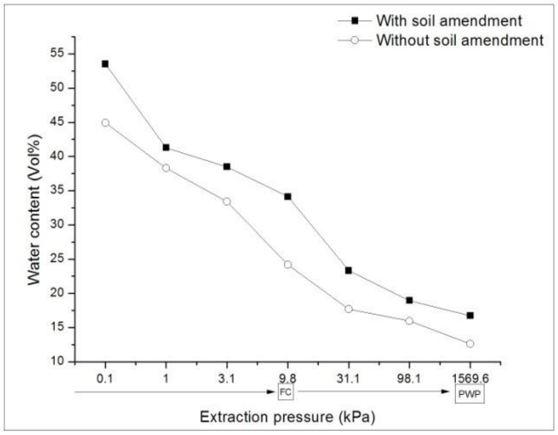

Fig. 2. Effects of soil amendment on water holding capacity in experimental soil.

IV. Conclusion

The present study indicated that under hot and dry conditions with coarse texture soil, more frequent water application (4-5 days) with less amount of each application was an appropriate practice for chili production. However, with the incorporation of soil amendment (coir dust) that could improve the soil available water holding capacity, the frequency of water application can be reduced (9-13 days) with little effect on chili. Fertigation improved all plant growth and yield components compared to soil application. Its effect on plant growth and yield was attributed to greater nutrient uptake and fertilizer use efficiency.

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