An Improvement of Optimal Allocation Water For Cultivating Supper Chilli

Niwat Phumiphan, Anongrit Kangrang and Worawat Sa-Ngiamvibool

Department of Civil Engineering, Faculty of Engineering, Mahasakham University, Kantharawichai, Maha Sarakham, 44150, Thailand.

Abstract: At present, Supper Chilli is important raw material to cook for most Thai people. They can widely growth in the northeast region of Thailand. However, there are many problems in product and growth because of insufficient water requirement. This paper improved the optimal allocation water for cultivating supper Chilli according to crop water requirement in all stages. The daily allocation plan to cultivate Supper Chilli was designed based on crop water requirement of accepted Penman-Monteith method using LP model. This daily plan was used to be the condition of finding optimal source of water (surface and ground water) to distribute for cultivation. The optimal sources of water with the optimal quantity of water were used to construct the control distribution system. There are five types of irrigation system that were conducted in the study including original irrigation, drip irrigation on surface, drip irrigation subsurface for 5% change of soil moisture content and long duration change of soil moisture content 10% and 20%. The Supper Chilli was cultivated in the all conducted systems. The yield products were measured and recorded. The results found that the LP model provided daily crop water requirement of the Supper Chilli equally Penman-Monteith equation. The suitable sources of water with quantity of require water were derived from optimization model. The yield products of the drip irrigation were higher than theirs existing irrigation methods. The yield products of the drip irrigation subsurface for 10% change of soil moisture content were the highest. In conclusion, optimal allocation water for cultivating Supper Chilli based on crop water requirement could be daily plan of cultivation that remarked the suitable sources of water. The crop water requirement of accepted Penman-Monteith method provided the highest crop benefit.

Keywords: linear programming, reference crop water requirement (ETo), supper chilli, soil moisture content.

INTRODUCTION

Chilli (Capsicum annuum) belongs to the genus Capsicum under Solanaceae family. The Chilli plant is a white flowered, dark green or purple leaved plant that grows up to 1.5 m in height. It is also called as hot pepper, cayenne pepper, sweet pepper etc. Five species of Capsicum are under cultivation, though a number of wild species have been identified recently. The major consumers of chilli in the world are India, China, Mexico, Thailand, United States of America, United Kingdom, Germany and Sweden. Nowadays, Supper Chilli is a necessary raw material to cook for most Thai people especially in northeast region. They can widely growth in the central of region all the times. The schedule of cultivation is planned before starting growth. Generally, crop harvesting is around 2 months. However, there are many problems in crop yield and growth such as an insufficient water requirement, high investment cost and high take care cost (man power, fertilize, pesticide) etc. To improve allocation water for cultivating Supper Chilli not only reduces cost of operation but also to promote famers who has a small farm in the northeast region of Thailand. For this reason, a farmer at the start of each irrigation season needs to have optimal allocation water and irrigation program which will minimize the irrigation cost.

An allocation resource under limited condition is one of the classical problems in water resources management. In particular, given the total available resources for example water, land area, pesticide, fertilize and manpower. To maximize the total profit of agricultural activities or to minimize irrigation cost are set as objective functions to solve this problem. With optimization techniques available; such as Linear Programming (LP), Dynamic Programming (DP) and Genetic Algorithm (GA), it is LP model that is more popular in allocation problems (Singh et al., 2001; Sethi et al., 2006). A linear programming is an optimization technique which widely used to allocate the limited water resources because of the proportionate characteristic of allocation problem (Panda et al., 1996; Salmon et al., 2001). Furthermore, the LP is easy to apply with the problem of irrigation planning using several available programs. The maximization benefit was set as the objective function based on the resources constraints. The constraint functions are linear equation for finding optimum crop pattern when given available water (Haouari and Azaiez, 2001; Babatunde et al., 2007).

Design distribution system which control water release based on total amount of potential evapotranspiration during considered period is necessary for scare water situation.
Generally, the yield response to water is estimated for each crop using the relationship between relative yield \((Y_a/Y_m)\) and relative evapotranspiration \((ET_a/ET_p)\) (Doorenbos and Kassam, 1979). A multiplicative form of previous Equation which covers all growth stages simultaneously was proposed by Rao et al., (1988). This multiplicative form should be used in optimization models and deficit irrigation planning (Kabosi and Kaveh, 2010). The relationship between crop yield and evapotranspiration as well as crop yield and applied irrigation on many crops were widely studied in the world (Zachariassen and Power, 1991; Boamah et al., 2010; Kangrang et al., 2011; Akinbile and Sangodoyin, 2011). Yield response factor varies depending on species, variety, irrigation method and management and growth stage when deficit evapotranspiration is imposed (Kirda, 2002; El-Sayed et al., 2009). However, the conjunctive use of surface water and ground is necessary in deficit water area. This concept should be promoted in the region where having more ground water potential (Kangrang et al., 2008).

This study thus improved the optimal allocation water for cultivating Supper Chilli according to total amount of potential evapotranspiration during considered period. An allocation L.P. model was applied to determine optimal irrigation plan. The minimizing the irrigation cost was an objective functions subject to constraints on availability of surface and ground water. There are five types of irrigation system that were conducted in the study including original irrigation, drip irrigation on surface, drip irrigation subsurface for 5% change of soil moisture content and long duration change of soil moisture content 10% and 20%. Crop yield and operation cost were recorded.

**MATERIALS AND METHODS**

**The Study Area:**

Chilli requires a warm and humid climate for its best growth and dry weather during the maturation of fruits. Chilli crop comes up well in tropical and sub-tropical regions, but it has a wide range of adaptability and can withstand heat and moderate cold to some extent. The crop can be grown over a wide range of altitudes from sea level up to nearly 2100 m above MSL. It can be grown throughout the year under irrigation.

The study area was carried out at a Supper Chilli farm in Roi-Et province, (in the central of the northeast region of Thailand) from 2009 to 2010. The annual rainfall varied during 1, 000-1, 300 mm. A temperature ranging from 25-35°C is ideal for chilli farm. The location map of farm is described in Fig 1. There are two seasons in this area, dry season and wet season. Dry season is from mid December to mid May and wet season is from mid May to mid December. Cultivation in wet season uses rainfall only, for dry season uses both surface water from irrigation system and ground water from small pump of the farm. The hydrologic and meteorological parameters of this area were collected such as temperature, relative humidity, solar radiation, wind speed and rainfall etc.

![Fig. 1: Location map of the study area.](image_url)
Determination of Actual Crop Water Requirement:
The daily allocation plan to cultivate Supper Chilli was designed based on crop water requirement of accepted Penman-Monteith method (Allen et al., 2006). This equation requires the hydrologic and meteorological parameters of cultivating area. The calculated ET$_o$ from Penman-Monteith equation is described as

$$\text{ET}_o = \frac{0.408\Delta (R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_a - e_d)}{\Delta + \gamma (1 + 0.34 U_2)}$$

(1)

where ET$_o$ is the grass reference evapotranspiration (mm d$^{-1}$), $\gamma$ is psychrometric constant (kPa °C$^{-1}$), $\Delta$ is slope vapor pressure curve (kPa °C$^{-1}$), $R_n$ is net radiation (MJ m$^{-2}$ d$^{-1}$), $G$ is soil heat flux (MJ m$^{-2}$ d$^{-1}$), $T$ is mean daily temperature (°C), $U_2$ is mean wind speed measurement at 2 m. height (ms$^{-1}$) and $e_a$-$e_d$ is vapor pressure deficit (kPa).

Actual crop water requirement during considered period ($Q_j^{ET}$) was calculated using the following equation,

$$Q_j^{ET} = \sum_{i=1}^{I} \text{ET}_{o,i} \times K_{c,j} \times A_i$$

(2)

In which $K_{c,j}$ is crop coefficient corresponding to the appropriate week of crop growth during day $j$, $A_i$ is area of crop cultivation zone $i$ and $I$ is total number of cultivation zone.

Determination Of Optimal Daily Plan:
This daily plan was used to be the condition of finding optimal source of water (surface and ground water) to pull for cultivation. The optimal sources of water with the optimal quantity of water were used to construct the control irrigation system.

The objective function consists of minimizing the irrigation cost ($Z$) subject to constraints on availability of surface and ground water and other inputs.

$$\text{Minimize } Z = \sum_{j=1}^{n} C_s q_{s,j} + \sum_{j=1}^{n} C_g q_{g,j}$$

(3)

In which $C_s$ is irrigation cost of using surface water during day $j$, $C_g$ is irrigation cost of using ground water during day $j$, $q_i$ is actual crop water requirement from surface water, $q_g$ is actual crop water requirement from ground water, $n$ is number of day for harvesting.

Irrigation cost is the cost calculating from water cost, preparing area, pesticide, fertilize and manpower. Crop water requirement, irrigation cost, crop yield, crop price and related data are described in table 1.

Table 1: Related Data of Supper Chilli.

<table>
<thead>
<tr>
<th>Type of Supper Chilli</th>
<th>Water requirement (mm./Rai)</th>
<th>Irrigation cost (Baht/Rai)</th>
<th>Yield (Kg/Rai)</th>
<th>Crop Price (Baht/Kg)</th>
<th>Benefit (Baht/Rai)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh</td>
<td>186.824</td>
<td>6,000 – 8,000</td>
<td>6,000 – 10,000</td>
<td>400 – 500</td>
<td>10,000 – 15,000</td>
</tr>
<tr>
<td>Dry</td>
<td>186.824</td>
<td>6,000 – 8,000</td>
<td>6,000 – 10,000</td>
<td>100 – 140</td>
<td>10,000 – 15,000</td>
</tr>
</tbody>
</table>

Note: 30 Baht ~ 1 US$, 1 Rai = 1,600 m$^2$, Crop water requirement for 57 days only

Minimization of the objective function is subject to the following constraints.

1. Water availability constraints, the crop water requirement from surface and ground water are greater or equal actual crop water requirement during day $j$.

$$q_{s,j} + q_{g,j} \geq Q_j^{ET}$$

(4)

2. Actual crop water requirement is greater or equal the maximum crop water requirement that provide the maximum crop yield.
The crop yield response to water was estimated using the relationship between relative yield and relative evapotranspiration as the following (Doorenbos and Kassam, 1979).

\[
Y_a = K_y \left(1 - \frac{ET_a}{ET_m}\right)
\]

where \(Y_a\) and \(Y_m\) are actual and maximum crop yields, corresponding to \(ET_a\) and \(ET_m\), actual and maximum evapotranspiration, respectively; and \(K_y\) is crop yield response factor.

**Design Irrigation System:**

There are 2 sources of irrigation water that using to cultivate Supper Chilli as present in Fig 2. Amount of water under crop water requirement will be distributed to 5 applied irrigations. This drip irrigation system was conducted on cultivation area of Supper Chilli in Roiet province. The automatic control system with soil moisture content sensor was set up for releasing water to cultivated area. There are five types of irrigation system that were conducted in the study including original irrigation, drip irrigation on surface, drip irrigation in subsurface, rapid change of soil moisture content and long duration change of soil moisture content. The Supper Chilli was cultivated in the all conducted system. The preparing irrigation area and distribution control system are shown in Fig 3 and Fig 4. The operating cost and crop yield were measured and recorded.

**Fig. 2:** Schematic diagram of experiment.

**Fig. 3:** Preparing irrigation area.

**Fig. 4:** Preparing distribution system.
RESULTS AND DISCUSSION

Determination of Actual Crop Water Requirement:

The calculated ET$_{0}$ from Penman-Monteith equation (Allen et al., 2006) considering hydrologic and meteorological parameters of study area and crop coefficient (Supper Chilli) are shown in Fig 5. They indicated that these values are small in the beginning and the highest during the fourth week then reducing until the ninth week. These trends varied on the growth stage of Supper Chilli. These calculated ET$_{0}$ were used to compute daily actual crop water requirement as present in Fig 6. The daily calculated crop water requirements were used to determine amount of water requirement of study area.

Fig. 5: Calculated ET$_{0}$ and Crop coefficient.

Determination of Optimal Daily Plan:

Fig 7 shows irrigation cost considering water surface water and ground water for each week. They present that irrigation cost of surface water during the study are higher than the irrigation of using ground water because of the characteristic of study area. These data were used to find the amount of the weekly crop water requirement and the optimal sources of water usage. This concept of conjunctive use of surface water and ground is performed because of having more ground water potential (Kangrang et al., 2008). With the objective function minimizing the irrigation cost subject to theirs constraints of LP model provided the optimal sources of water with the optimal quantity of water as described in Fig 8. These conditions were applied to control distribution water system with different irrigation systems. The five types of irrigation system such as original irrigation, drip irrigation on surface, drip irrigation subsurface for 5% change of soil moisture content and long duration change of soil moisture content 10% and 20% were performed with cultivating Supper Chilli.

Fig. 6: Daily actual crop water requirement.
Fig. 7: Irrigation cost of using surface water and ground water.

Fig. 8: Weekly calculated crop water requirement from surface water and ground water.

**Crop yield and Benefit of Applied Irrigation Systems:**

The growths of Supper Chilli in the study area are present in Fig 9. Table 2 present crop yield during harvest of each applied irrigation system for 4 times. They present that the applied existing irrigation (with farmer experiences) provided the lowest yield on 4 times of harvest. This system obtained water insufficiently during the growth because of using farmer experiences. They didn’t concern calculated crop water requirement and growth stage. Therefore Supper Chilli obtained water insufficiently some day and received water over demand in some time. These perform reached to high operation cost consequently. An insufficient crop water requirement condition promotes low crop yield condition according to equation of Doorenbos and Kassam (1979) and the others study (Zachariassen and Power, 1991; Boamah et al., 2010; Akinbile and Sangodoyin, 2011).

Fig. 9: Supper Chilli in study area.
Table 2: Crop yield of applied irrigation systems during harvest.

<table>
<thead>
<tr>
<th>Applied irrigation systems</th>
<th>Crop yield during harvest (Kg/Rai)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1&lt;sup&gt;st&lt;/sup&gt;</td>
</tr>
<tr>
<td>Existing irrigation (original irrigation)</td>
<td>97.36</td>
</tr>
<tr>
<td></td>
<td>6.46</td>
</tr>
<tr>
<td>Drip irrigation on surface</td>
<td>100.62</td>
</tr>
<tr>
<td></td>
<td>6.56</td>
</tr>
<tr>
<td>Drip irrigation subsurface for 5%</td>
<td>101.33</td>
</tr>
<tr>
<td>change of soil moisture content</td>
<td>5.84</td>
</tr>
<tr>
<td>Drip irrigation subsurface for 10%</td>
<td>101.89</td>
</tr>
<tr>
<td>change of soil moisture content</td>
<td>6.75</td>
</tr>
<tr>
<td>Drip irrigation subsurface for 20%</td>
<td>100.23</td>
</tr>
<tr>
<td>change of soil moisture content</td>
<td>6.18</td>
</tr>
</tbody>
</table>

Note: 1 Rai = 1,600 m<sup>2</sup>, μ = mean, σ = standard deviation

Fig 10 shows crop benefit of each applied irrigation system for 4 times of harvest during the study. They present that the applied existing irrigation (with farmer experiences) provided the lowest benefit on 4 times of harvest. For the others applied irrigation system can obtain water equal daily calculated crop water requirement. Hence, these systems got maximum crop yield according previous study (Kirda, 2002). How every, crop yield and crop benefit of these system are different. The drip irrigation in subsurface for 10% change of soil moisture content provided the highest crop benefit in 4 times of record. In addition, the conjunctive use of surface water and ground of applied system reached using water from the lowest irrigation cost.

Fig. 10: Crop benefic of each applied irrigation system.

Conclusion:

This paper determined daily optimal allocation water for cultivating supper Chilli subject to water that was estimated using the relationship between relative yield and relative evapotranspiration as well as considered conjunctive use of surface water and ground water. The obtained daily plan was used to construct the control distribution water system. There are five types of irrigation system that were conducted in the study including original irrigation, drip irrigation on surface, drip irrigation subsurface for 5% change of soil moisture content and long duration change of soil moisture content 10% and 20%. The Supper Chilli was cultivated in all conducted systems. The crop yield were measured and recorded.

The results found that the LP model provided daily crop water requirement of the Supper Chilli that came from the lowest irrigation cost. The crop yield of the drip irrigation were higher than theirs existing irrigation methods. The proposed method guaranteed obtaining maximum crop yield because of considering crop water requirement of accepted Penman-Monteith method. The crop yields of the drip irrigation in subsurface for 10% change of soil moisture content was the highest. In conclusion, optimal allocation water for cultivating Supper Chilli based on crop water requirement could be daily plan of cultivation that remarked the suitable sources of water.
ACKNOWLEDGEMENTS

The authors would like to acknowledge the financial support by TRF-Master Research Grant of Thailand (MAG Window I 2009, Ref.No. MRG-W1525E110). The authors wish to sincerely thank to the Agricultural Farm, Roi-Et province, Thailand for supporting partial grant and study area.

REFERENCES


