Application of FAO-CROPWAT Modelling on Estimation of Irrigation Scheduling for Paddy Cultivation in Batticaloa District, Sri Lanka

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ABSTRACT
Agriculture sector is one of the main sources of income in the North eastern and some of the North western parts of Sri Lanka. Over the past decade, many countries around the world have witnessed a growing scarcity and competition for water among different users. Since Agriculture is the major user of water, improving agricultural water management is essential to any irrigation management approach specially to apply the exact amount of water to the field in order to meet crop water requirement. This study aims to estimate water requirement of rice by using the model CROPWAT. According to the study, effective rainfall was found to be 601mm and 133 mm in Maha and Yala season respectively. Total crop water requirements are 349 mm and 436 mm in Maha and Yala season respectively. Irrigation scheduling carried out by CROPWAT revealed that, the gross irrigation requirement is 473 mm and net irrigation requirement is 331 mm. Net scheme irrigation requirements are 40, 106, 100 and 22 mm per month in May, June, July and August respectively. Further, flow of net scheme irrigation requirements is found to be 0.15, 0.41, 0.37 and 0.08 l/s/ha in May, June, July and August respectively. Therefore, the model for planning of irrigation water requirements of rice is very important for efficient utilization of water and to meet the possible change of climate in agricultural sector.

Key words: CROPWAT, Water requirement, Effective rainfall, Irrigation scheduling, Rice.

INTRODUCTION
Rice, the staple food of Sri Lanka, is the most important source of employment and income of the rural population (Tao et al., 2008). Sri Lanka’s rice sector has achieved spectacular results in the last 5 decades. The total paddy production increased rapidly and reached 4.18 million Mt in 2010 (Central Bank of Sri Lanka, 2010). The per capita consumption of rice is 105 kg/year (average of 2004-2008) or about 300 grams per day, which provides about 1,000 calories or almost half of the average total daily calorie intake (Department of Census and Statistics, Agriculture Census, 2010). Global population is expected to increase by about 30% by the year 2030 and as a result, demand for food will increase (FAO, 2000). Major constrains to meet the increasing food demands of the population are scarcity of irrigation water and land availability for crop production (Ali, 2008). Water is important for plant growth and food production. Since, there is competition between municipal, industry users and agriculture for the finite amount of available water, estimating irrigation water requirements accurately is important for water project planning and management (Michael, 1999). Severe water scarcities are the major problem in many countries particularly in Sri Lanka. The uneven distribution and pattern of rainfall and low water holding capacity of soils, soil moisture stress during dry season are some of the major limiting factors for higher productivity in the nation.

In Sri Lanka, so many strategies have been developed and being executed with the aim of developing the Agriculture sector which is one of the main sources of income. The traditional methods have been practiced in Agriculture by farmers for a long period. With the emergence of new technologies and its widespread use, the use of those technologies in Agriculture sector will probably create a positive effect on the growth and development of Agriculture (Singh et al., 2015). A possible approach to overcome constraints could be through improving performance of adopted irrigation systems or introductions of better ones. Further, efficient use of irrigation water based on the crop water requirement is essential to save water in the agricultural field. Therefore, field measurements are needed to measure the crop water requirement of a particular crop. Owing to practical difficulties in obtaining accurate field measurements for $\text{ET}_C$, prediction methods are commonly used. However, these methods often need to be applied under climatic and agronomic conditions different from those
under which they were originally developed. Testing the accuracy of the methods under a new set of conditions is laborious, time consuming and costly. To overcome such difficulties, guidelines were formulated by FAO to calculate ET<sub>c</sub> of crops under different climatic and agronomic conditions (Teare and Peet, 1983).

Many advanced and novel scientific irrigation scheduling techniques have been developed in the past three decades. However, the adoption by farmers is low, especially in developing countries (Annandale et al., 2011). The major reasons for low adoption are reported to be lack of soil water parameters and weather conditions and complexity of the techniques such that farmers are confused by choice and do not understand the difference between the different scheduling techniques (Stirzaker, 2006), failure of the scientist to understand the situation of farmers and the constraints under which they operate (Vanclay, 2003).

Batticaloa district has many agriculture activities such as paddy, vegetables, chilies and other crop cultivation. Paddy is the major crop under cultivation by the farmers in this district. Their basic economy and food are mainly depending on rice production. The study area’s paddy cultivation is also affected by the rainfall fluctuation and the scarcity of irrigation water which lead to number of problems in paddy production and human life. It is also a major problem in primary economic activities. Therefore, improved practices on cultivation and the adoption of new technology against water scarcity are important to get optimum yield of the crop. In this view, efficient application of water to increase the paddy production in sustainable manner.

**Study location**

This study is conducted in Batticaloa district that belongs to eastern province of Sri Lanka. The geographical coordinates of the Batticaloa district are 7°34′2″ N and 81°41′2″ E.

**Selection of model**

In this study, CROPWAT model was selected for the computation of crop water requirement and irrigation scheduling for rice in Batticaloa district. CROPWAT 8.0 was used to calculate reference evapotranspiration using climatic variables such as maximum and minimum temperature, sunshine hour, rainfall, relative humidity and wind speed.

**CROPWAT model input data**

The basic input data for CROPWAT model are the climatic parameters which are required for calculating Reference Evapotranspiration. Researchers proposed several methods to determine evapotranspiration out of which the Penman-Monteith Method (FAO, 1998) has been recommended as the appropriate combination method to determine the crop water requirements using climatic data such as temperature, humidity, sunshine and wind speed. FAO Penman-Monteith method (FAO, 1998) was used in the present study for determining reference crop evapotranspiration (ET<sub>r</sub>) since it has been reported to provide values that are very consistent with actual crop water use data worldwide (Allen et al., 2006). Secondary data such as station data (Table 1), climate data (Table 2), rainfall data (Table 3), crop data (Table 4) and soil data (Table 5) were used for the study.

**Table 1: Coordinates of study area.**

| Country     | Sri Lanka       |
|-------------|-----------------|
| Station     | Batticaloa      |
| Altitude    | 8.53 m          |
| Latitude    | 7.34° N         |
| Longitude   | 81.41° E        |

**Table 2: Batticaloa district climate data (Average of last 30 years).**

| Month   | Maximum Temperature (°C) | Minimum Temperature (°C) | Mean RH (%) | Wind speed (km/h) | Sunshine hours (Hours) |
|---------|--------------------------|--------------------------|-------------|-------------------|------------------------|
| January | 27.53                    | 23.21                    | 81          | 14.3              | 6.4                    |
| February| 28.20                    | 23.22                    | 80          | 13                | 7.9                    |
| March   | 29.70                    | 23.90                    | 79          | 10.9              | 8.8                    |
| April   | 31.11                    | 24.90                    | 78          | 9.5               | 8.6                    |
| May     | 32.40                    | 22.50                    | 73          | 9.2               | 8.4                    |
| June    | 33.60                    | 25.40                    | 68          | 9.3               | 8.4                    |
| July    | 33.20                    | 25.00                    | 69          | 9.8               | 8                     |
| August  | 32.50                    | 24.80                    | 71          | 9.7               | 8.3                    |
| September| 32.10                   | 24.60                    | 73          | 9.7               | 8.3                    |
| October | 30.60                    | 24.10                    | 79          | 9.5               | 7.5                    |
| November| 29.00                    | 23.50                    | 82          | 10.4              | 6.7                    |
| December| 27.81                    | 23.20                    | 83          | 12.9              | 5.6                    |

**Source:** Meteorological Department, Sri Lanka.
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Station data

Source

Geospatial data from survey department and https://www.distancesto.com/coordinates/lk/batticaloa-latitude-longitude/history/15542.html

Climate data

Following long-term meteorological data were collected from meteorological department.
- Maximum Temperature and Minimum Temperature (degree Celsius)
- Maximum Relative Humidity and Minimum Relative Humidity (%)
- Wind Speed (km/h)
- sunshine Hours (Hours)

Rainfall Data

Average monthly rainfall data were collected from meteorological department to find out the effective rainfall to calculate the crop water requirement and irrigation scheduling.

Determination of Effective Rainfall

Many water studies have used the CROPWAT 8.0 model to estimate monthly effective rainfall. Although the software offers several alternative methods, the method referred to as the "USDA SCS method" (USDA Soil Conservation Service method) has generally been used due to its simplicity; being only a function of monthly precipitation and not requiring local calibration. The original USDA SCS method estimates monthly effective rainfall from gross rainfall, soil water holding capacity and crop evapotranspiration. A similar study was carried out to determine the water requirement of main crops in the perumal tank irrigation command area in Cuddalore district of Tamilnadu. In the method reference crop evapotranspiration (Reference Evapotranspiration) was determined using the FAO Penman-Monteith method and the effective rainfall was calculated using USDA S.C method (Saravanan and Saravanan, 2014). Monthly rainfall data are required to calculate the effective rainfall (Allen et al., 1998 and Smith, 1991). For this study, the USDA SCS method provided in the CROPWAT model was used to calculate the effective rainfall on monthly basis using the following criteria.
- When total rainfall is<250 mm, effective rainfall (ER) is given by the following equation:
  \[ ER = TotalR \times (125 - 0.2 \times TR) / 125 \]  
  Equation 01
- When total rainfall is>250 mm, effective rainfall is given by the following equation:
  \[ ER = 125 + 0.1 \times Total \text{ Rainfall} \]  
  Equation 02

Crop data

The crop type, variety and development stage should be considered when assessing the evapotranspiration from crops grown in large, well-managed fields. Crop coefficient values (Kc) were taken from available published data and FAO CROPWAT 8.0 default value. Based on the published information following crop data were collected.

Soil data

The soil module is essential data input, requiring the general soil data like total available water (TAW), maximum infiltration rate, maximum rooting depth, initial soil moisture depletion. In case of calculation of rice water requirement, additional soil data are required such as drainable porosity, critical depletion for puddle cracking, water availability at planting, maximum water depth. In Batticaloa, the coastal belt of eastern province of Sri Lanka, the predominant soil

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### Table 3: Average monthly rainfall data (Last 30 years).

| Month    | Rainfall (mm) |
|----------|---------------|
| January  | 279.1         |
| February | 178.3         |
| March    | 84.8          |
| April    | 72.4          |
| May      | 31.2          |
| June     | 18.5          |
| July     | 37.0          |
| August   | 61.7          |
| September| 61.7          |
| October  | 178.1         |
| November | 285.2         |
| December | 429.8         |

Source: Meteorological Department, Sri Lanka.

### Table 4: Crop data.

| Particulars                  | Initial | Development | Mid | Late | Total |
|------------------------------|---------|-------------|-----|------|-------|
| Kc value                     | 0.5     | -           | 1.05| 0.7  | -     |
| Stages (days)                | 20      | 25          | 35  | 25   | 105   |
| Rooting depth (m)            | 0.10    | -           | 0.60| 0.60 | -     |
| Critical depletion (fraction)| 0.20    | -           | 0.20| 0.20 | -     |
| Yield response               | 1.00    | 1.09        | 1.32| 0.50 | 1.10  |

Source: (Sahindomi et al., 2013) and (Doorenbos and Kassam, 1979)

### Table 5: Soil data.

| Soil Texture | Sandy regosol |
|--------------|---------------|
| Total available soil moisture (FC- WP) | 100 mm/m |
| Maximum rain infiltration rate | 30 mm/day |
| Maximum rooting depth | 90 cm |
| Initial soil moisture depletion (as % TAM) | 0 % |
| Initial available moisture | 100 mm/meter |

Source: FAO CROPWAT 8.0, 2009

collected in the present study and used as input data for CROPWAT model for further analysis.
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There are chances for water saving. For agricultural production, effective precipitation refers to the portion of rainfall that can be effectively stored in the root zone after the losses such as runoff and deep percolation (Layheang et al., 2015). Therefore, paddy cultivation needs irrigation water in mid of the year (April to August) but rain water is sufficient in November to February for paddy cultivation in Batticaloa District. During the dry period higher percentage of available rainfall is effectively stored in the root zone because, the absorbance capacity of soil is high due to dry nature of the soil. During rainy season, especially during December and January soil reached its saturation capacity very often, therefore there is a chance for runoff losses. Therefore, percentage of effective rainfall in relation to the receiving rainfall is less during this period compared to the dry season months.

RESULTS AND DISCUSSION

**Effective Rainfall**

Table 6 shows the average monthly rainfall and effective rainfall in mm. Effective rainfall was calculated by USDA method in CROPWAT 8.0. Batticaloa district receives around 1060.1 mm effective rainfall per year. Highest value of effective rainfall is observed in December (168 mm) and lowest value of effective rainfall is observed in June (18 mm). Rainfall reduces irrigation water requirement on the ground. Therefore, there are chances for water saving. For agricultural production, effective precipitation refers to the portion of rainfall that can be effectively stored in the root zone after the losses such as runoff and deep percolation (Layheang et al., 2015). Therefore, paddy cultivation needs irrigation water in mid of the year (April to August) but rain water is sufficient in November to February for paddy cultivation in Batticaloa District. During the dry period higher percentage of available rainfall is effectively stored in the root zone because, the absorbance capacity of soil is high due to dry nature of the soil. During rainy season, especially during December and January soil reached its saturation capacity very often, therefore there is a chance for runoff losses. Therefore, percentage of effective rainfall in relation to the receiving rainfall is less during this period compared to the dry season months.

**Crop water requirement in Yala season**

Table 7 shows the crop water requirement during planting to harvesting period (May to August). ETc value recorded as the range in between 2.18 to 4.5 mm/day during the period of May to July. In the initial stage, the rice needs only about 2.18 mm per day as the water requirements. Crop water requirement increase from 2.18 to 4.38 mm/day during initial stage to mid stage respectively. Then, it further increases from 4.45 mm to 4.47 mm/day during the entire period of the mid-season stage where the rice consumes much water for growing and reaches its maximum height. Finally, the water requirement of rice decreases from 4.5 to 3.19 mm per day in the late-season, the period of ripening. This is also the time for draining water for the harvest. Similar data was also recorded by Layheang et al., 2015.

**Irrigation scheduling**

**Irrigation scheduling in Yala season**

Irrigation is required when rainfall is insufficient to compensate for the water lost by evapotranspiration. Table 8 and 9 shows the computation of net irrigation requirement, gross irrigation requirement and irrigation flow rate for
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Table 8: Summary of Irrigation scheduling in Yala season.

|                         | Total gross irrigation | Total net irrigation | Total irrigation losses | Actual water use by crop | Potential water use by crop | Efficiency irrigation schedule | Efficiency rain |
|-------------------------|------------------------|----------------------|-------------------------|--------------------------|-----------------------------|-------------------------------|----------------|
| Total gross irrigation  | 472.5 mm               |                      |                         |                          |                             |                               |                |
| Total net irrigation    | 330.7 mm               |                      |                         |                          |                             |                               |                |
| Total irrigation losses | 0.0 mm                 |                      |                         |                          |                             |                               |                |
| Actual water use by crop| 373.8 mm               |                      |                         |                          |                             |                               |                |
| Potential water use by crop| 373.8 mm             |                      |                         |                          |                             |                               |                |
| Efficiency irrigation schedule | 100%                  |                      |                         |                          |                             |                               |                |
| Deficiency irrigation schedule | 0%                   |                      |                         |                          |                             |                               |                |

Table 9: Irrigation scheduling in Yala season.

| Date   | Day | Stage     | Rainfall mm | Ks fraction | Depletion % | Net Irrigation mm | Gross Irrigation mm | Flow l/s/ha |
|--------|-----|-----------|-------------|-------------|--------------|-------------------|---------------------|-------------|
| 4-May  | 3   | Initial   | 0           | 1           | 33           | 4.4               | 6.2                 | 0.24        |
| 6-May  | 5   | Initial   | 0           | 1           | 28           | 4.4               | 6.2                 | 0.36        |
| 8-May  | 7   | Initial   | 0           | 1           | 25           | 4.4               | 6.2                 | 0.36        |
| 10-May | 9   | Initial   | 0           | 1           | 22           | 4.4               | 6.2                 | 0.36        |
| 15-May | 14  | Initial   | 0           | 1           | 25           | 6.4               | 9.1                 | 0.21        |
| 19-May | 18  | Initial   | 0           | 1           | 21           | 6.4               | 9.1                 | 0.26        |
| 22-May | 21  | Development | 0         | 1           | 22           | 7.3               | 10.5                | 0.4         |
| 25-May | 24  | Development | 0         | 1           | 21           | 7.8               | 11.1                | 0.43        |
| 30-May | 29  | Development | 0         | 1           | 25           | 10.4              | 14.8                | 0.34        |
| 2-June | 32  | Development | 0         | 1           | 21           | 9.8               | 14                  | 0.54        |
| 5-June | 35  | Development | 0         | 1           | 22           | 10.8              | 15.4                | 0.59        |
| 9-June | 39  | Development | 0         | 1           | 21           | 11                | 15.8                | 0.46        |
| 12-June| 42  | Development | 0         | 1           | 22           | 12.4              | 17.6                | 0.68        |
| 15-June| 45  | Development | 0         | 1           | 22           | 13.2              | 18.8                | 0.72        |
| 19-June| 49  | Mid        | 0           | 1           | 25           | 15.2              | 21.7                | 0.63        |
| 22-June| 52  | Mid        | 0           | 1           | 22           | 13.3              | 19                  | 0.73        |
| 25-June| 55  | Mid        | 0           | 1           | 22           | 13.4              | 19.1                | 0.74        |
| 29-June| 59  | Mid        | 0           | 1           | 24           | 14.2              | 20.3                | 0.59        |
| 2-July | 62  | Mid        | 0           | 1           | 22           | 13.4              | 19.1                | 0.74        |
| 5-July | 65  | Mid        | 0           | 1           | 22           | 13.4              | 19.1                | 0.74        |
| 9-July | 69  | Mid        | 0           | 1           | 22           | 13.4              | 19.1                | 0.55        |
| 12-July| 72  | Mid        | 0           | 1           | 22           | 13.4              | 19.1                | 0.74        |
| 15-July| 75  | Mid        | 0           | 1           | 22           | 13.3              | 19.1                | 0.74        |
| 19-July| 79  | Mid        | 0           | 1           | 22           | 13.3              | 19.1                | 0.55        |
| 22-July| 82  | End        | 0           | 1           | 21           | 12.7              | 18.2                | 0.7         |
| 25-July| 85  | End        | 0           | 1           | 21           | 12.5              | 17.8                | 0.69        |
| 29-July| 89  | End        | 0           | 1           | 21           | 12.5              | 17.8                | 0.51        |
| 2-August| 93 | End        | 0           | 1           | 26           | 15.4              | 22.1                | 0.64        |
| 6-August| 97 | End        | 0           | 1           | 24           | 14.3              | 20.4                | 0.59        |
| 10-August| 101| End        | 0           | 1           | 24           | 14.3              | 20.4                | 0.59        |
| 14-August| 105| End        | 0           | 1           | 5            |                    |                     |             |

Table 10: Irrigation scheme in Yala season.

| Precipitation deficit | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|-----------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1. Rice               | 0   | 0   | 0   | 0   | 39.8| 106.3| 99.8| 21.8| 0   | 0   | 0   | 0   |
| Net scheme irrigation requirement in mm/day | 0   | 0   | 0   | 0   | 1.3 | 3.5 | 3.2 | 0.7 | 0   | 0   | 0   | 0   |
| in mm/month           | 0   | 0   | 0   | 0   | 39.8| 106.3| 99.8| 21.8| 0   | 0   | 0   | 0   |
| in l/s/h              | 0   | 0   | 0   | 0   | 0.15| 0.41| 0.37| 0.08| 0   | 0   | 0   | 0   |
| Irrigated area        | 0   | 0   | 0   | 0   | 100 | 100  | 100 | 100 | 0   | 0   | 0   | 0   |
| Irrigation requirement for actual area (l/s/h) | 0   | 0   | 0   | 0   | 0.15| 0.41| 0.37| 0.08| 0   | 0   | 0   | 0   |
irrigation scheduling from planting date to harvesting date during Yala season. As per irrigation scheduling carried out by CROPWAT it shows that gross irrigation requirement is 472.5 mm and net irrigation requirement is 330.7 mm.

### Irrigation scheme in Yala season

Table 10 shows computation of irrigation scheme for paddy cultivation in Yala season. Irrigation scheme includes precipitation deficit, net scheme irrigation requirement, irrigated area and irrigation requirement for actual area. Net scheme irrigation requirements are 39.8, 106.3, 99.8 and 21.8 mm per month in May, June, July and August respectively. Flow of net scheme irrigation requirements are 0.15, 0.41, 0.37 and 0.08 l/s/ha in May, June, July and August respectively.

### Comparison of crop water requirement in Maha and Yala season

According to the analyzed data effective rainfall is 601.4 and 298.5 mm/ decade in Maha and Yala season respectively and total crop water requirement are 349.2 and 436.7 mm/ decade in Maha and Yala season respectively (table 11 and 12). According to the ETc and effective rainfall calculations, irrigation requirement in Yala season is 298.5 mm to complete the paddy production (table 12). This data shows that, in Yala season (dry season), the crop water requirement is higher than Maha season (rainy season). The (FAO, 2009) also reported that, crops grown in the dry season needs more water than those grown during the rainy season.

### CONCLUSIONS

This study concluded that the model for planning of irrigation scheduling of rice is very important for efficient utilization of water and to meet the possible change of climate in agricultural sector. Therefore, one of the best strategies to achieve this is the application and utilization of the rapid growing technologies in information and communication technology. Therefore, introduction and use of this CROPWAT software is very useful in water management of paddy as well as other crops cultivated in the dry zone of Sri Lanka. It is also suggested to study further on the water requirement of different varieties of the paddy as well as vegetable crops at different zones or districts.

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