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Estimating Evapotranspiration for Irrigation Scheduling by Using Atmometers

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ABSTRACT

High-value short-duration crops were commodities that were planted in upland production areas however, if there is no basis for irrigation scheduling other than soil characteristics and plant reaction to low water consumption, results in losses. The objectives were to evaluate the depth of water for irrigation based on Atmometer reading, assess the growth and yield of organically grown crops at a different level using button drip irrigation system, and to evaluate the cost and economic returns. The study was conducted at BPSU Bangkal, Abucay, Bataan (N 14°46' East 120°30') with a total area of 240 m^2 where the three crops were planted equally at three replications. The total rainfall depth at BPSU-AWS Station for October 2021 to November 2022 was 2614.6 mm during the two-season study period. There were three crops raised (eggplant, wax pepper, and tomato). Foliar organic fertilizer was used in fertigation system. Three treatments were subjected for verification (T1 – Irrigate up to 80% of Atmometer reading, T2 - Irrigate up to 100% of Atmometer Reading, and T3 – Irrigate up to 120% of Atmometer). The eggplant of Treatment 1 had the best in terms of weight per fruit (106.0 grams), Treatment 2 was the tallest (74.5 cm), and Treatment 3 had the best harvest (458 pcs). Eggplant was resistant to drought even supplemented wih 30% of its evapotranspiration loss. Treatment 2 of Wax Pepper had 7.5 grams per fruit and also exhibited the most number of fruit harvested. Wax Pepper should be supplemented with 50% of its evapotranspiration loss. Treatment 2 of tomatoes had the most in terms of weight per fruit (50.1 grams), hieght (45.5 cm), and number of fruits harvested. Tomatoes should be supplemented with 50% of their evapotranspiration loss. Crops evapotranspiration loss should be supplemented at 50% to 100% to attain maximum production.

INTRODUCTION

As most of the water withdrawn by agriculture is lost through evaporation and transpiration, irrigation for crop production constitutes the most agricultural water worldwide. In the Philippines, agricultural irrigation accounts for 82% of the overall freshwater withdrawals. Hence, efficient and scientific utilization of water for irrigation is necessary to effectively address the increasing cost and shortage of irrigation water. To do this, irrigation systems must be made to minimize water wastage. In conjunction with efficient fertigation systems to avoid fertilizer wastage, this is a requirement for optimum crop production (Octura, *et al.*, 2020).

Knox, *et al.* (2011) suggested that atmometers would be an appropriate tool for use in humid environments on deep-rooting crops (potatoes) with long growing seasons where the irrigation interval is not less than 7 days. Care would need to be exercised using modified atmometers on short-season shallow-rooting crops with short irrigation intervals in which errors in ET estimation would have a more dramatic impact.

To maximize the applied water to a specific crop, there should be a reference for crops' evapotranspiration (ET) rate for irrigation scheduling. However, the consumptive use of crops was presented in total ET for the entire production without specific consumptive use for every growth stage or even daily water use.

The information on the ET rate of crops in terms of irrigation water can save water that can be used for other purposes. The saved water could be used for succeeding crop production through proper cropping patterns. However, there must be a partial economic analysis for decisions making before engaging in crop production.

Establishing an irrigation system in the rolling and upland production area significantly impacts production and income because the application of water needed by the plants supplements their water requirement through the reading of an Atmometer as the basis.

The result of the study would be disseminated to rainfed upland farmers to increase their production, multiply their produce, and additionally net income hence they were not hesitating to produce crops because irrigation water applied to high-value crops was based on atmometer reading therefore minimal water would be used for crop production.

In crop production, water for irrigation was the primary need in the upland area. We should establish an irrigation water reservoir as a small farm reservoir (SFR) or concrete water tank as a source of irrigation water for crop production (irrigation system). Pressurized or gravity for dripper could be done.

With increasing population, lowland conversion, and climate change, crop producers must increase and sustain the crops that produce at any places possible for

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cultivation. Sustainability in the supply of crop production for families (small scale) could be happened by increasing cropping season and adding production areas even in the rolling areas but through the availability of irrigation water. Water productivity would be increased. It was good to sustain the family's needs.

Rainfed vegetable farmers and even plantations could adopt the technology due to technology objectives that were fertigation (irrigation and foliar organic fertilizer application) of crops using an atmometer as a reference, utilized crop production area, and sustainability of crop production and results to increased production and income through increasing water productivity.

LITERATURE REVIEW

Evapotranspiration

Evapotranspiration (ET) is an important process in the agricultural water cycle and surface energy balance, resulting from an interaction between soil, vegetation, and the atmosphere. ET is separated into two processes whereby water is vaporized from the soil surface by evaporation and the transpiration of the leaf loses water. ET varies depending on environmental variables such as air temperature, air humidity, wind speed, vapor pressure deficit, soil water content, direct solar radiation, and plant and crop management characteristics. As water shortage especially in the dry season is common in Thailand, available water for crop field irrigation is becoming limited. In addition, extreme climatic events, such as drought and shifts in rainfall distribution patterns, have been widespread in recent decades and imposed a significant threat to water resources management, especially for agricultural use. As a result, quantifying ET is crucial for water resource and agricultural management (Singta *et al.*, 2018).

Estimation of Evapotranspiration

According to Octura *et al.* (2020), irrigation for crop production constitutes the most agricultural water worldwide. As most of the water withdrawn by agriculture is lost through crop evapotranspiration (ETC), efficient water management requires accurate and reliable estimation of ETC. To date, available methods for estimating ETC require expensive devices and extensive meteorological information, which become a problem in areas with no instruments and with limited data.

The study suggests that atmometers would be an appropriate tool for use in humid environments on deep-rooting crops with long growing seasons in which the irrigation interval is not less than 7 days. However, the representative crop (potatoes) is deep rooting (≈0:7m) with relatively long minimum irrigation intervals (> 5 days). Care would need to be exercised using modified atmometers on short-season shallow-rooting crops with short irrigation intervals in which errors in ET estimation would have a more dramatic impact (Knox *et al.*, 2011).

ET is either quantified using expensive lysimeters that are only typically used on research sites or estimated using equations based upon climatological inputs that often overpredict ET and/or require extensive inputs. For this reason, soil moisture sensors for ET estimation were explored and compared with measured ET for three lysimeter configurations (Hess *et al.*, 2021).

As stated by Reyes-Gonzalez *et al.* (2017), spatial and temporal ETa values were observed at different crop growth stages using the METRIC model. The ETa values derived from METRIC were higher than ETa values estimated with atmometers.

Application of ET Rate

A datalogger linked between the atmometer and the existing irrigation control timer recorded daily evaporation, calculated irrigation schedules, and operated irrigation valves to apply sufficient irrigation to replace the previous day's estimated water use. Seasonal water consumption was reduced by up to 70% compared to the normal practice of irrigating all season long at the peak use rate (Parchomchuk, P. *et al.*, 2000).

According to Peters and Okwany (2021), atmometers estimate the crop water use of a reference crop of short grass and are a measurement of the weather and climate effects on crop water use. They do not take into account how crops use different amounts of water during their various growth stages. For example, a recently emerged corn plant does not use as much water as a fully grown corn plant. To be used accurately, the atmometer water evaporation values must be multiplied by crop coefficients that are specific to the crop and that crop's stage of growth.

With a proper regression equation and a good calibration, atmometers could be used to estimate ET for crop water requirements where evapotranspiration estimates are not available from a weather station (Diop *et al.*, 2015).

METHODOLOGY

Includes and presents the materials used, the crop used in the study, the site identified, the preparation of the experimental area, data gathered and monitored, the experimental design, and data analysis.

The framework (Figure 1) illustrate and discuss the input, process, and output of the study. The identified area was cleared, crop establishment, instrumentation, and farm inputs (INPUTS). During crop development, the crop will be maintained and managed through scheduled irrigation based on ET, fertilization, and pest management, including gathering crop growth parameters (PROCESS). As the result, there will be established data on crop ET rate, irrigation scheduling, crop growth performance, yield performance, and Benefit-Cost Ratio using the Atmometer (OUTPUT).

MATERIALS

a. Drip Irrigation. This will be established to water the crop at specific conditions (9.0l ph).

b. Pressurized Pump. Used to deliver pressurized irrigation water.

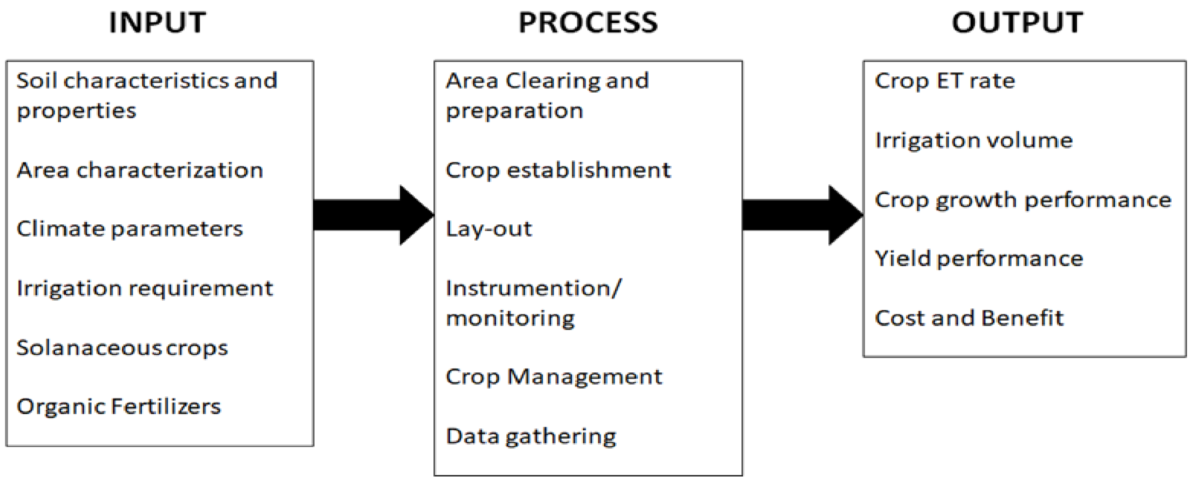

Figure 1: Conceptual Framework

c. Atmometer. Use to measure the crop evapotranspiration.

d. Crops. Wax Pepper (Siling Panigang), eggplant, and tomato are used.

e. HDPE Pipe. This was laid out in the production area where irrigation equipment establishes.

f. Soil Moisture Meter. Used to measure and monitor the soil moisture for irrigation scheduling.

g. Organic Fertilizer. Used as a nutrient supplement for the crop.

h. Automatic weather station. Instrument where agro-climatic data are recorded and to be used for analysis.

Site Identification

The area was identified within the Campus for the study with a 17%-30% slope for the agro-forestry development however it was terraced. Three (3) terraced areas was utilized for crop production. The area was a 240 square-meter demonstration site located in Organic Crop Demonstration Area, BPSU.

Instrumentation

The dripper was established within a 240 m^2 plot within the terraced area following the crop layout. Moisture meter was used to monitor soil moisture. Atmometer was also established for every treatment basis for irrigation scheduling.

Figure 2: Crops, Dripper, and Atmometer

Crop Production Establishment

The identified area was cleared. Remove the vegetative covers through manual hoeing. High value crops like Eggplant (Fortuner F1), tomato (Diamante) and Wax Pepper (Siling panigang) was planted along the established terraced area in triangular method single row at 0.6 m per plant and 1.0 m between row replicated into three.

Crop Maintenance

The crop established was maintained. Regular weeding was done including irrigation based on the crop water requirement from Atmometer and soil moisture content. Pest and diseases management will be observed and control. The fertilizer used was organic and applied through the fertigation method.

Data Gathering and Collection

Data to be gathered and collected will be ET depth, depth of rainfall from AGROMET Station, soil moisture, irrigation volume and irrigation time, crop growth parameters, and yield.

Rainfall

It was collected every 8 AM and 2 PM every day at the AGROMET Station.

Evapotranspiration

It was monitored and recorded from the atmometer reading for a specific time interval. Daily ET was monitored and total evapotranspiration for every week was recorded.

Irrigation time and frequency

It was dependent on the atmometer reading every 7-days irrigation interval.

Growth parameters

Height was gathered and measured from eggplant, wax pepper, and tomato.

Yield

Harvested fruits from eggplant, wax pepper, and tomato were recorded. The average weight every treatment and the number of fruit picked were also recorded.

Experimental Design and Layout

The compiled data from the study was analyzed using a Randomized Completely Block Design (Figure 3), statistical analysis for mean differences, and using F-Test for the significance of the gathered data. Economic analysis was presented using the Cost and Return Analysis.

Layout:

Treatment 1, T1 – 80% of crop water requirement

Treatment 2, T2 – 100% of crop water requirement

Treatment 3, T3 – 120% of crop water requirement

Figure 3: Experimental Layout

RESULT AND DISCUSSION

Rainfall

The area has two distinct seasons, the dry season which starts from November to May, and the rainy season from June to October of the year. Table 1 was the depth of rainfall in BPSU-AWS Station from October 2021 to November 2022

Table 1: Rainfall depth (mm) during the study period

	2021	2022
Jan		21.6
Feb		10.2
Mar		43.4
Apr		39.2
May		167.6
Jun		195.2
Jul		440.0
Aug		415.4
Sep		572.4
Oct	211.8	394.2
Nov	10.2	38.4
Dec	55.0	
Sub-Total	**277.0**	**2,337.6**
Total		**2,614.6**

Irrigation Depth

Table 4-6 data was taken during the flowering stage of crops using the Atmometer (Evapotranspiration Gage). The irrigation depth for the crops was based on the Atmometer reading (Figure 4-6). The irrigation frequency was every seven (7) days. The dripper's specification was 9.0 liters per hour. The mean ET for Eggplant was 3.4 cm for 7 days. It takes 1 hr and 52 min to drip 2.8 cm for 0.6 m2 area (Table 2 and 3 for Eggplant - Treatment 1). The mean evapotranspiration depth of the Tomato was 2.7 cm for 7 days. The irrigation time for a depth of 3.2 (Treatment 3, Table 2 and 3) to irrigate 0.6 m2 was 2 hr and 8 min.

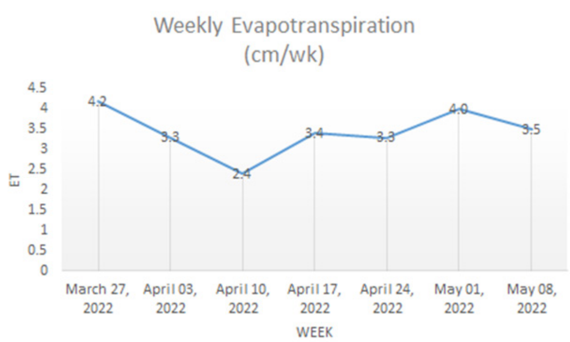

Figure 4: Evapotranspiration of Eggplant

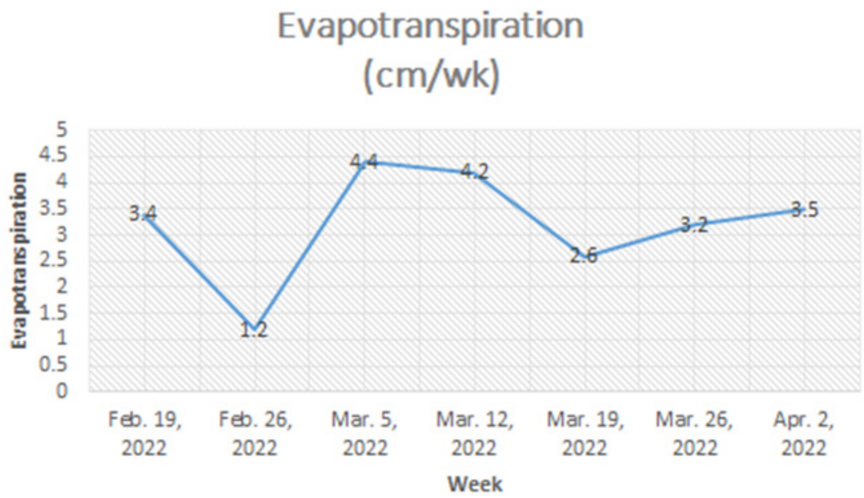

Figure 5: Evapotranspiration of Wax Pepper

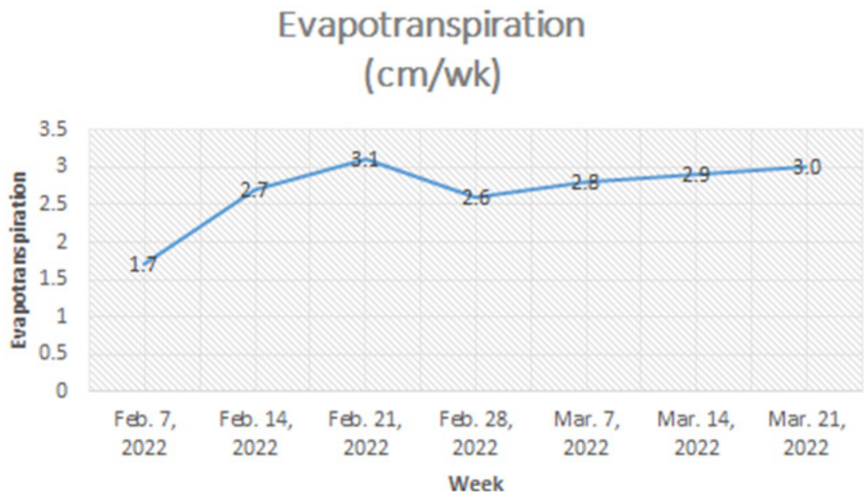

Figure 6: Evapotranspiration of Tomato

Table 2: Mean weekly evapotranspiration

Crops	Total 7-day Evapotranspiration (cm/week)							Total	Mean
	1	2	3	4	5	6	7		
Eggplant	4.2	3.3	2.4	3.4	3.3	4.0	3.5	24.1	3.4
Wax Pepper	3.4	1.2	4.4	4.2	2.6	3.2	3.5	22.5	3.2
Tomato	1.7	2.7	3.1	2.6	2.8	2.9	3.0	18.8	2.7

Table 3: Weekly depth of irrigation water

Crops	Total 7-day Evapotranspiration (cm/week)							Total	Mean	T1 80%	T2 100%	T3 120%
	1	2	3	4	5	6	7					
Eggplant	4.2	3.3	2.4	3.4	3.3	4.0	3.5	24.1	3.4	2.8	3.4	4.1
Wax Pepper	3.4	1.2	4.4	4.2	2.6	3.2	3.5	22.5	3.2	2.6	3.2	3.9
Tomato	1.7	2.7	3.1	2.6	2.8	2.9	3.0	18.8	2.7	2.1	2.7	3.2

Growth Performance

Table 4 was the maximum height (mean) of crops. Eggplant has 74.5 cm high (Treatment 2 – 100% of ET Rate). Wax Pepper has 45.5 cm high (Treatment 2 – 100% of ET rate). Tomato has 80.2 cm high (Treatment 2), however, it was almost the same with Treatment 1.

Table 4: Crops height (cm) during the fruiting stage

	Eggplant	Wax Pepper	Tomato
Treatment 1	67.2	37.6	80.0
Treatment 2	74.5	45.5	80.2
Treatment 3	70.0	41.5	77.0

Yield Performance

The harvested fruit of crops was recorded such as the number of pieces picked and weight (Table 5-7). Harvested eggplant was 153.144 kg (1577 fruits) from 135 plants (45 plants per Treatment - Table 5) at around 97.1 grams per fruit (mean). Treatment 1 was the heaviest among treatments but had fewer number fruits. Treatment 3 has the most fruits.

The wax pepper harvested was 52.2 kg from an 87.0 m2 area with 135 plants (Table 6). The harvested number of wax pepper fruits was 7,101 at 7.4 grams per fruit (mean). The tomato fruits harvested were 268.299 kg from an 87.0 m2 area with 135 plants (Table 7). The harvested number of tomato fruits was 5564 at 48.2 grams per fruit (mean).

Table 5: Harvested eggplant

Eggplant		Wt (grams)	pc/s	grams/pc
Treatment	1	50,534.0	493	102.5
	2	48,759.0	518	94.1
	3	53,851.0	566	95.1
Total		**153,144.0**	**1577**	
Mean				**97.1**

Table 6: Harvested wax pepper

Wax Pepper		Wt (grams)	pc/s	grams/pc
Treatment	1	12,939.0	1832	7.1
	2	22,932.0	3043	7.5
	3	16,329.0	2226	7.3
Total		**52,200.0**	**7101**	**7.4**
Mean				**97.1**

Table 7: Harvested Tomato

Tomato		Wt (grams)	pc/s	grams/pc
Treatment	1	82,642.0	1710	48.3
	2	97,817.0	1952	50.1
	3	87,840.0	1902	46.2
Total		**268,299.0**	**5564**	
Mean				**48.2**

Cost and Benefit

Initial cost covered the materials which include irrigation facilities like pumps, PE pipes, drippers, valves, filters, etc. Depreciation, interest on investment, repair, and maintenance were included in the fixed cost while variable costs were farm inputs and labor costs for crop production. Gross income (Table 8) comes from sales of different crops. The eggplant has Php10,672.15 net income (Php160.00/kg), 23.5% was the return on investment (ROI) and it will pay back the initial cost within 4.3 cropping season. Wax Pepper has Php14,616.00 net income (php250.00/kg), a return of investment was 1.7% and has long period of paying the investment capital. Tomato production has Php18,364.99 net income (Php120.00/kg), a 40.4% return on investment, and it takes 2.5 cropping seasons to pay the investment or capital.

Table 8: Crops height (cm) during the fruiting stage

Basic Computation (PhP)	Eggplant	Wax Pepper	Tomato
I. Initial	45,479.70	45,479.70	45,479.70
II. Fixed cost			
a. Depreciation cost (5 % of initial cost)	2,273.99	2,273.99	2,273.99
b. Interest on Investment (5 % of initial cost)	2,273.99	2,273.99	2,273.99
c. Repair and Maintenance (2 % of initial cost)	909.59	909.59	909.59
Useful Life, years	5	5	5
Total Annual fixed cost	5,457.56	5,457.56	5,457.56
III. Variable Cost			
a. Planting materials, fertilizers, etc.	1,040.00	1,040.00	1,040.00

b. Labor Cost	7,333.33	7,333.33	7,333.33
Total Variable Cost	8,373.33	8,373.33	8,373.33
Total Annual Cost	13,830.89	13,830.89	13,830.89
IV. Gross Income	24,503.04	14,616.00	32,195.88
V. Net Income	10,672.15	785.11	18,364.99
VI. ROI (%)	0.235	0.017	0.404
VII. Payback Period (per Cropping)	4.3	57.9	2.5

CONCLUSION

Eggplant production could be raised better than other high-value crops in terms of net income. Eggplant has 3-4 months of life. The 2.8 cm/week (80% of Evapotranspiration rate per week) irrigation water supplemented was comparable with 100% or more. Water productivity was 270 liters (Treatment 1) to 370 liters (Treatment 3) of irrigation water to produce a kilogram of eggplant. The net income would be Php1,226,683.91 per hectare.

Wax pepper production was not feasible due to low net income and it takes longer cropping season to recover the initial investment or capital. Even though the price is high but the production was low.

Tomato production has a net income of Php18,364.99 for 80 m^2 (268.3 kg at Php120.00/kg). The water productivity in the production of tomatoes was 123 liters (Treatment 1) to 134.15 liters (Treatment 2) of irrigation water to produce a kilogram of tomato. Lower tomato production and harvested if more irrigation water was applied (more than Evapotranspiration).

RECOMMENDATION

Crop production in the upland rolling area crop should consider elevation, land configuration, weather, crop characteristics and planting materials, farmer's management, planting method, irrigation method, the basis for irrigation volume, and timing of planting/transplanting.

Tomato has better net income if considers the variety, characteristics, irrigation method, planting/harvesting season, and irrigation timing. The use of the best irrigation method would increase production with the aid of an atmometer. This would measure the depth of evapotranspiration of crops equal to the depth of irrigation. Also increased water productivity.

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