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Development and Calibration of Automated Class A Evaporimeter

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Abstract

Automatic evaporimeter was developed using a set of sensors and transducer such as carbon resistor, semi-carbon conductor and lighting diode-4 v 60 mm amp to start the mechanism of automated measurement. The working principle of the instrument was developed using 10 values of initial and final lighting points (ILP, FLP) and the rate of evaporation from the Class A Pan was obtained in physical variables (Voltage and refractive values). The instrument was calibrated using different statistics metrics. The instrument's time response to a step change in water level from the evaporation was calibrated to every level (0.1 cm) of water change in the pan. Automated evaporimeter has the capacity to measure daily maximum evaporation value of 0.3 cm and this corresponds to the refractive value (√e) of 15.0 and voltage (v) of 225.6 v respectively.

Keywords: Evaporimeter; Sensitivity; Water level; Calibration; Sensor

Introduction

Evaporation is an important component of hydrological cycle and its rate is being determined by the prevailing weather. Accurate measurements of environmental variables such as rainfall, runoff, soil moisture, evaporation rates, minimum and maximum temperatures are essential aspects of Agro-meteorological research that is important in agricultural, environmental and water resource modeling.

The current available methods for measuring rates of evaporation are limited. Unfortunately, the three accurate direct methods of measurement available i.e., weighing lysimeter, Bowen ratio and eddy flux instrumentation, are unstable for monitoring evaporation as a routine direct measurement at meteorological enclosures because of high demand of complex computations. The World Meteorological Organization (WMO) has recommended that the evaporation pan be adopted as the standard instrument for crop water use determination, the best known of the pans are the "class A" evaporation pan and the "sunken Colorado pan" [1]. The pan has proved its practical value and has been used successfully to estimate reference evapotranspiration by observing the evaporation loss from a water source and applying empirical coefficients to relate pan evaporation to reference evapotranspiration (ET) [1]. However, routine measurement of evaporation in Nigeria still suffers from poor coverage and non-uniform instrumentations [2].

It is observed that in humid climates "class A" pan evaporation measurements were reasonable estimates of evapotransporation when soil water was not restricting plant growth [2]. Because of its nature, evaporation from water surfaces or water bodies is rarely measured directly, except over relatively small spatial and temporal scales [3]. Evaporation from water is most commonly computed indirectly by one or more techniques, these include pan coefficients measured pan evaporation, water balance, energy balance, mass transfer and combination of various techniques [4,5]. The selection of the "best" technique to use for a particular computation is largely a function of the data availability type or size of the water body, and the required accuracy of the estimated evaporation.

The most commonly used method in the world for estimating evaporation from small, shallow water bodies, is to measure evaporation from a standard pan like the "class A" pan and then multiply by a co-efficient. Recently, precision agriculture technology has made significant advances in the area of irrigation scheduling. In developed countries, equipment for continuous monitoring of climate conditions is now available to help farmers determine and know how much water to apply and when to apply it. It was established that frequent measurement of evaporation rates from an automated class A evaporation pan can accurately estimate reference evapotranspiration and can be used as an irrigation scheduling tool [1,5,6].

Therefore, the objective of this study is to develop and calibrate a cheap electronic device for measuring daily evaporation rates under prevailing climatic conditions with high precision.

Materials and Methods

Description of developed automated class a evaporation pan

A Class A evaporation pan was made of 3 mm sheet gauge with diameter and depth of 101.1 cm and 20.5 cm respectively. The pan has a capacity of 0.145 m^3 and stilling well diameter and depth of 5.5 cm and 20.5 cm. The assembled pan was placed on a smooth-surface wooden box covering surface area 1.09 m^2 and at 0.91 m high. An automated water level sensor was mounted by the front side of the evaporation pan as shown in Figure 1. Figures 2a and 2b show the assemblage of evaporation class A pan [7].

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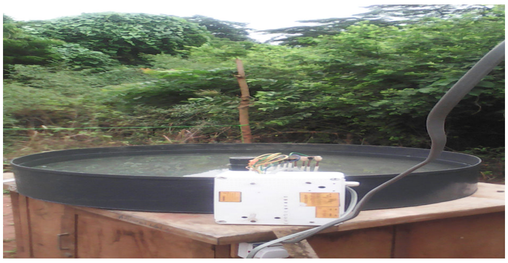

Figure 1: Developed automatic evaporimeter (Class A Evaporation pan).

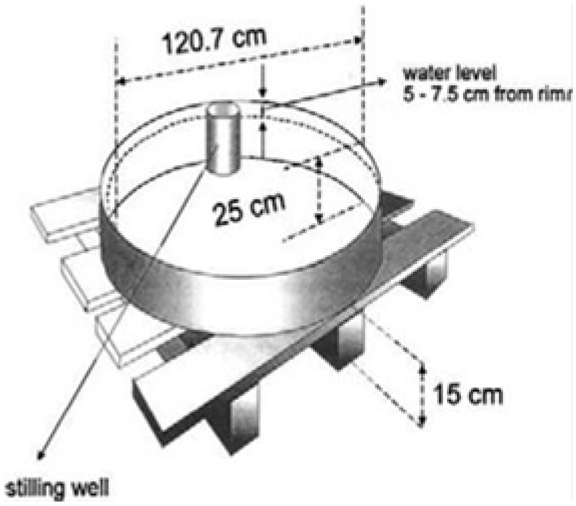

Figure 2a: Class A evaporation pan.

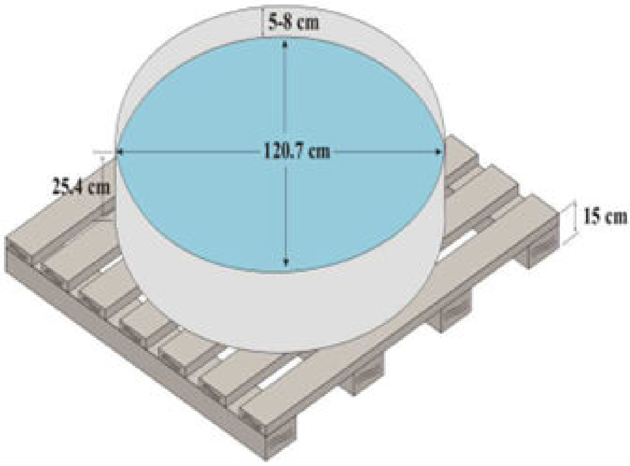

Figure 2b: Class A evaporation pan.

Instrumentation and calibration of class A evaporation pan

The automatic evaporimeter makes use of a sensor which consists of a set of sensitive probes (aluminum probe). The probes have direct contact with water such that when a probe touches the liquid, it converts the physical variable (water) to electrical variable. In this very work, the electrical variable refers to change in resistance from 100 kΩ to infinity (Ohm) which in turn is used to activate the control line of the display unit. As the respective probes touch the liquid (water), each unit is activated. The process is reversed when the probe gets disengaged from the physical variable and the control unit sends a signal to the physical variable (water).

The control unit is made of:

i. A carbon resistor (100 KΩ); and

ii. A semi-carbon conductor diode (IN4007).

The display unit is made up of light emitting diode (4 v 60 mini amp). The sensor is a metallic conductor that is specifically chosen so that it would not corrode as a result of emanate aluminated conductor. The sensor has ten (10) graduation i.e., ten (10) metallic cables and each one stands for 0.1 mm, so that when there is evaporative decrease of 0.1 cm in the water level inside the evaporating pan, one bulb goes. If the evaporative decrease is 0.3 cm, 3 bulbs go off and each bulb is equivalent to 75.2 V and refractive index value (√e) of 8.67. The index is dimensionless. The bulb lighting mechanism shows the result of the probe contact with the physical variables at a given point in time. The feature in plate 1 shows the developed automatic evaporimeter (Class A pan).

Data collection: The experiment was conducted at the Experimental and Research Farm of Auchi Polytechnic, Auchi, located at Etsako-West, its geographical coordinates are 7°4'0" North, 6°16'0" East and its original name (with diacritics) is Auchi, 20 km away from Aviele. The climatic classification of Auchi is divided dry and wet seasons with an average air temperature of 30.4°C and annual precipitation and relative humidity of 1256.2 mm and 65.9% respectively. Evaporation depths were taken with the aid of automated evaporimeters to the nearest centimeter.

Data analysis: The generated evaporative data from the gauge and automated evaporimeters were applied to calibrate the automated instrument using signal 1.0; power and logarithm components of excel 2013 version. The coefficient of determination was used for validation statistics. CROPWAT version 8.1 was used to estimate the solar radiation R_s and evapotranspiration (ET_o).

Results and Discussion

Developed automatic Class A Evaporation Pan was used to measure evaporation rate for 49-day. Evaporation rate was measured in voltage (v) and refractive index (√e) value as shown in Table 1. Daily meteorological data such as T_{max} and T_{min}, relative humidity, sunshine hour and wind speed were measured and recorded throughout the period of experimentation as indicated in Table 1. On the first day 13/06/2015 the value of T_{max} and T_{min} temperature were 24.5°C and 34.2°C. These values corresponded to 20.9 cm and 20.7 cm of IER, FER and DER value of 0.2 cm respectively. This analog concept of Class A Evaporation was simulated with 10 values of ILP, 8 FLP, 150.4 and 12.3 refractive value respectively. Figure 3 shows the output of equipment calibration using different statistics validations. Strong agreement was obtained with power and logarithm with R^2=0.999, 0.869 and 16.4

value of calibration value was obtained indicating the sensitivity of the instrument to evaporation value of 0.1 cm.

S/N	DATE	TMIN	TMAX	TMEAN	IER	FER (cm)	DER	ILP	FLP	V(v)	√e	S.H	RH
1	13/06/15	24.5	34.2	29.3	20.9	20.7	0.2	10	8	150.4	12.3	8.0	70.7
2	14/06/15	24.5	30.4	30.4	20.6	20.4	0.2	10	8	150.4	12.3	9.0	69.6
3	15/06/15	24.5	36.1	30.3	20.3	20.1	0.2	10	8	150.4	12.3	8.0	69.6
4	16/06/15	24.5	35.2	29.9	20.9	20.7	0.2	10	8	150.4	12.3	74.5	70.1
5	17/06/15	24.4	34.3	29.4	20.9	20.7	0.2	10	8	150.4	12.3	9.0	70.6
6	18/06/15	24.2	30.2	27.2	20.9	20.8	0.1	10	9	75.2	8.7	8.3	72.8
7	19/06/15	24.5	33.1	28.8	20.9	20.8	0.1	10	9	75.2	8.7	7.0	71.2
8	20/06/15	20.5	35.4	27.9	20.9	20.7	0.2	10	8	150.4	12.3	7.0	72.1
9	21/06/15	24.3	34.2	29.3	20.9	20.7	0.2	10	8	150.4	12.3	8.0	70.7
10	22/06/15	24.5	35.1	29.8	20.6	20.4	0.2	10	8	150.4	12.3	9.0	70.1
11	23/06/15	24.5	35.2	24.9	20.9	20.7	0.2	10	8	150.4	12.3	7.4	70.2
12	24/06/15	24.5	35.0	29.8	20.9	20.7	0.2	10	8	150.4	12.3	8.2	70.5
13	25/06/15	24.5	34.4	29.5	20.9	20.8	0.1	10	9	75.2	8.7	8.2	71.2
14	26/06/15	24.5	33.2	28.5	20.9	20.7	0.2	10	8	150.4	12.3	7.4	72.1
15	27/06/15	24.5	31.3	27.9	20.6	20.3	0.3	10	7	225.6	15.0	8.0	71.7
16	28/06/15	24.5	32.1	28.3	20.7	20.6	0.1	10	9	75.2	8.7	8.1	71.1
17	29/06/15	24.5	33.2	28.9	20.9	20.8	0.1	10	9	75.2	8.7	7.5	71.7
18	30/06/15	24.5	32.1	28.3	20.8	20.6	0.2	10	8	150.4	12.3	8.3	72.7
19	1/07/15	23.2	31.4	27.3	20.9	20.7	0.2	10	8	150.2	12.3	7.4	72.1
20	2/07/15	24.5	31.3	27.9	20.8	20.7	0.1	10	9	75.2	8.7	7.4	72.1
21	3/07/15	20.5	32.1	26.3	20.8	20.7	0.1	10	9	75.2	8.7	8.0	73.7
22	4/07/15	24.5	32.3	28.4	21.0	20.9	0.1	10	9	75.2	8.7	7.5	71.6
23	5/07/15	20.5	34.5	27.5	20.8	20.7	0.1	10	9	75.2	8.7	7.3	72.5
24	6/07/15	24.5	33.0	28.8	20.9	20.8	0.1	10	9	75.2	8.7	7.4	71.2
25	7/07/15	20.5	33.3	26.9	20.9	23.8	0.1	10	9	75.2	8.7	8.3	72.1
26	7/07/15	24.5	34.2	29.4	20.9	20.7	0.2	10	8	150.4	12.3	7.5	70.6
27	9/07/15	24.5	33.5	29.0	20.9	20.8	0.1	10	9	75.2	8.7	8.0	72.1
28	10/07/15	24.2	32.4	28.3	20.9	20.8	0.1	10	9	75.2	8.7	8.2	71.7
29	11/07/15	24.5	34.3	29.4	20.8	20.7	0.1	10	9	75.2	8.7	8.3	70.6
30	12/07/15	24.5	33.1	28.8	20.9	20.8	0.1	10	9	75.2	8.7	8.5	71.2
31	13/07/15	24.5	32.4	28.5	20.8	20.6	0.2	10	8	150.4	12.3	8.0	71.5
32	14/07/15	24.5	34.1	29.3	20.9	20.7	0.2	10	8	150.4	12.3	8.3	70.7
33	15/07/15	24.3	33.0	28.7	20.9	20.8	0.1	10	9	75.2	8.7	7.5	71.3
34	16/07/15	24.2	33.2	28.9	20.9	20.8	0.1	10	9	75.2	8.7	8.5	71.1

35	17/07/15	34.5	32.3	28.4	20.9	20.7	0.2	10	8	150.4	12.3	7.5	71.6
36	18/07/15	24.0	33.3	28.2	20.9	20.8	0.1	10	9	75.2	8.7	7.4	71.8
37	19/07/15	24.2	31.5	27.9	20.9	20.8	0.1	10	9	75.2	8.7	8.2	72.1
38	20/07/15	23.5	30.2	26.9	20.9	20.7	0.2	10	8	150.4	12.3	8.2	73.1
39	21/07/15	24.5	33.1	28.8	20.9	20.8	0.1	10	9	75.2	8.7	8.2	71.2
40	22/07/15	24.0	32.3	28.2	20.9	20.7	0.2	10	8	150.4	12.3	7.5	71.8
41	23/07/15	23.2	31.2	27.2	20.9	20.8	0.1	10	9	75.2	8.7	7.5	72.8
42	24/07/15	20.2	35.2	27.7	17.5	14.5	2.0	10	8	150.4	12.3	8.0	72.3
43	25/07/15	27.0	35.3	31.2	14.5	14.2	0.3	10	7	225.6	15.0	8.2	68.8
44	26/07/15	20.0	35.0	27.5	14.5	14.2	0.3	10	7	225.6	15.0	8.1	72.5
45	27/07/15	26.0	31.0	28.5	14.5	14.2	0.3	10	7	225.6	15.0	7.0	71.5
46	28/07/15	24.2	31.3	27.8	14.5	14.3	0.2	10	7	225.6	15.0	7.2	72.2
47	29/07/15	23.3	35.4	29.4	15.5	14.3	0.2	10	8	150.4	12.3	7.5	70.6
48	30/07/15	24.5	25.2	29.9	14.5	14.3	0.2	10	8	150.4	12.3	7.2	70.1
49	31/07/15	20.1	34.3	27.2	14.5	14.3	0.2	10	8	150.4	12.3	7.3	72.8
Source: Generated data from developed automatic Evaporimeter and metrological field, 2015.													

Table 1: Results of automatic Evaporimeter (Class A Pan). Note: T_{min}=Minimum temperature 0°C, T_{max}=Maximum temperature 0°C, AveT=Average mean temperature 0°C; IER=Initial evaporation value (cm), FER= Final evaporation value (cm), DER=Difference in evaporation values (cm), ILP=Initial lighting points; FLP=Final lighting points, V=Voltage output (v), (·)=Refractive index, S.H=Sunshine hours, R.H=Relative humidity.

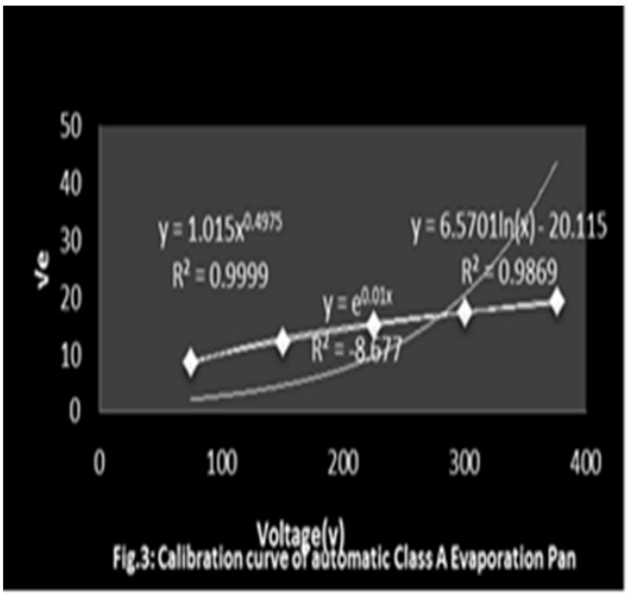

Figure 3: Calibration curve for automated Class A Pan.

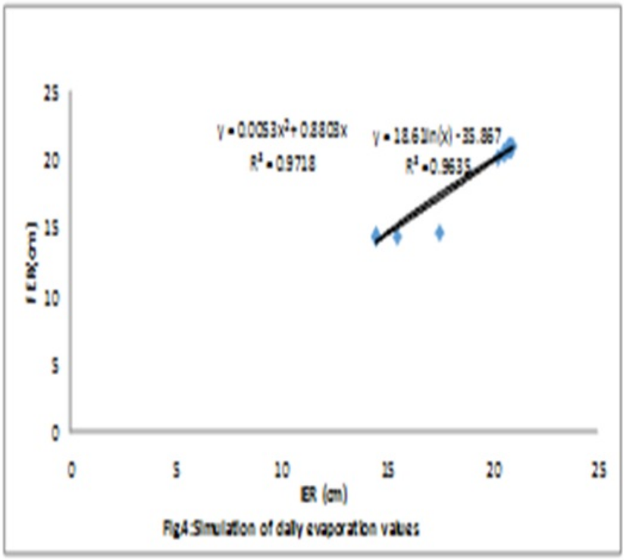

Figure 4: Relationship between (IER) and (FER).

Statistics validation (R^2) in Figure 4 shows that there was relationship between the initial evaporation reading (IER) and final evaporation reading (FER) with R^2=0.9718 and 0.9635 for linear and logarithm trend analysis respectively. However, it is revealed that air temperature is not the only factor influencing evaporation rate. On (27/06/2015) evaporation rate of 0.3 cm/day was recorded against T_{min} and T_{max} Temperature of 24.5°C and 31.3°C which corresponded to 225.6 v and refractive index value of 15.0 respectively. While on 25/06/2015, T_{min} and T_{max} of 24.5°C and 34.5°C were recorded. These values corresponded to evaporation rate of 0.1 cm/day, 75.2 v and refractive value of 8.7. Therefore, the accuracy of automatic Class A Evaporation was evaluated at ± 0.018 cm.

Generated data obtained from automatic evaporimeter and field meteorological measurements were used to run the Crop, Water and Soil model (CROPWAT version 8.1). Average solar radiation (R_s) and evapotranspiration (ET_o) of 19.6 MJ/m^2/day and 4.12 mm/day were produced as shown in Figure 5 show the simulation of output for solar radiation (R_s) and reference evapotranspiration (ET_o).

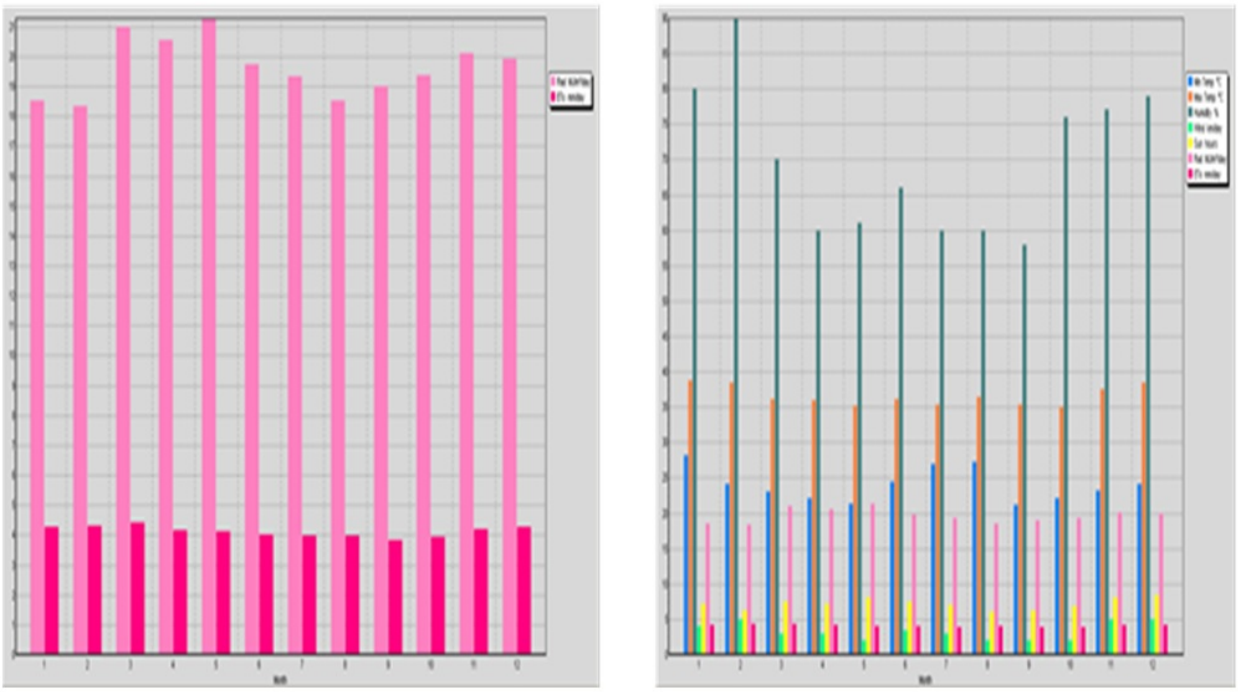

Figure 5: Output of CROPWAT simulation.

Conclusion

Direct measurement of evaporation rate in most cases does not provide a realistic result because of possible human error. However, it is unproductive to establish integrated water resource management and also estimate crop water requirement for agricultural production. A pan evaporation method is useful for getting the result in a short time in irrigation scheduling and water resources modelling and management. There are a lot of limitations using evaporation pan which affects the output of the result. The developed automated Class A evaporation pan accurately measures evaporation depth using aluminium probe sensors. The instrument has a measuring accuracy of ± 0.018 cm, evaporation depth of 0.1 cm, voltage (V) and refractive value of 75.2 V and 8.7 respectively. Accurate data generated from the instrument would be applied in running the physics-deterministic model for flow regime, soil erosion management, and precision agricultural system.

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