Design and Construction of a Small Scale Combined Weighing and Non-Weighing Lysimeter

ABSTRACT

Field experiment was conducted to study the consumptive use of water leaf (Talinum triangulare) on a constructed small scale combined weighing and non-weighing Lysimeter. This study considered the design and construction of a small scale lysimeter that combined the characteristics of a weighing and non-weighing.The main components of the lysimeter facility are mild steel, load cell, Arduino nano, micro secure digital (Micro SD) card, liquid crystal display (LCD) screen, real time clock (RTC) with model DS1307, moisture sensor, inner cylinder and outer cylinder. The installation depth of 0.4572m with a known rectangular floor was constructed to house the outer cylinder height of 167.8mm with diameter 309.4mm, inner cylinder height of 355.6mm with diameter 304.8mm and a hole of 2mm perforated at the bottom of the inner cylinder for easy drainage. The results on the data logged shows how much water is required for plant root extraction at various irrigation rates. The combined weighing and non-weighing lysimeter serve the purposes of determining the soil-water balance and water consumptive use of crop.

Keywords: Evapotranspiration, loamy soil, moisture sensor, load cells, water leaf

1. INTRODUCTION

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Surface energy balance is critical in crop production for monitoring water consumption and analyzing daily and seasonal water budgets (French et al., 2012). Water exchange between the soil surface and the atmosphere is critical f production, particularly during lengthy dry seasons (Malek et al., 1999). Several technological development on lys soil moisture depletion method, eddy correlation technique, water balance component analysis, energy-mass exc and crop coefficient method has been considered for estimating water loss of plant in agricultural fields evapotranspiration. Obviously, lysimeter is the most common equipment used for direct measurement of crop evapotranspiration and water balance components among the technologies listed (Igbadun, 2012).The water balance in the soil and crop evapotranspiration determine through the combined lysimeter, influences irrigation schedule and water usage efficiency in soil (Mohamed, 2011; Meena et al., 2015). A lysimeter is a vessel containing local soil that is placed with its top flush on the ground surface to examine several stages of the hydrological cycle, such as infiltration, runoff, evapotranspiration, and the removal of soluble elements in drainage. lysimeter is a one-of-a-kind tool for irrigation engineers to provide optimal water resource planning for agricultural productivity.

Field study by Mohamed (2011) reported that to calibrate and assess proposed vegetative water usage models, lysimeter data is combined with environmental and meteorological data. The crop water requirements for growth performance is very important when designing an efficient irrigation system. As the amount of water consumed by vegetation for transpiration on the development of plant tissues and the unavoidable evaporation of soil moisture, snow, and captured precipitation connected with vegetable growth. This is the most accurate indicator of how much water is required for plant root extraction at various irrigation rates. Lysimeters of different types have been used to measure and study water use for a variety of crops. Several studies on crop water use in many different locations and growing environments with crop-coefficient curves been developed. From the experimental work of Piccinni et al. (2002), the results from one environment where different types of lysimeters have been used to regulate water usage in a range of crops.

Similar research with 131 citation by Piccinni et al. (2009) on the determination of growth-stage-specific crop coefficients of maize and sorghum. Crop-coefficient curves have been generated from several studies on crop water use in a variety of locations and growth situations. According to Piccinni et al. (2002) research, results shows that one setting may not be

Comment [G1]: References must be indicated by number in the text

Comment [G2]: All references in the paper to be indicated by number in the text easily transferred to another due to soil differences and air temperature. Installing lysimeters and gathering water use data for local conditions provides the data needed to design curves that are appropriate for the area. According to Weihermueller et al. (2007), the name "lysimeter" refers to a variety of targets such as suction cups, flux meters, and other devices. It's also worth noting that lysimeter kinds differ depending on the research topic. Although, there are two types of lysimeters namely weighing and non-weighing lysimeter with different sizes and shapes. Some are so small and are known as micro lysimeters or mini-lysimeter with varied design and depth used to measure evaporation of water conducted from several field experiments (Todd et al., 2006). The design variability is influenced by prevailing weather and climatic condition of the study area and the soil type (Bhantana & Lazaovitch, 2010). Water leaf is widely grown in tropical region like the Niger Delta as leaf vegetable, its medicinal and nutritive value cannot be overemphasized (Udom et al., 2013; Uko et al., 2013) due to its role in maintaining the cardiovascular system. Therefore, this study estimate water consumptive use of water leaf on a small scale combined weighing and non-weighing lysimeter capable of data logging.

2. MATERIALS AND METHODS

Comment [G3]: Methodology

Study Area

Field experiment was conducted at the Rivers State Demonstration Farm, Rivers State University, where the fabricated small scale device capable of combining both characteristics of a weighing and non-weighing lysimeter was experimented. Port Harcourt is within the humid tropical climatic region characterized by two distinct seasons (wet and dry seasons) chart 1. The demonstration farm coordinate is between 4°48'22.50"N and 6°58'5.74"E with an altitude of 274mm above mean sea level; and an average annual rainfall of 2310.9mm. The wet season occurs mainly between March and October while the dry season is experienced during the remaining months of the year (November to February). The study area is endowed with sandy loam soil (Uko et al., 2016; Dumkhana & Ekemube, 2020) with an area of $1m^2$ cleared of vegetation in preparation for the installation of the lysimeter.

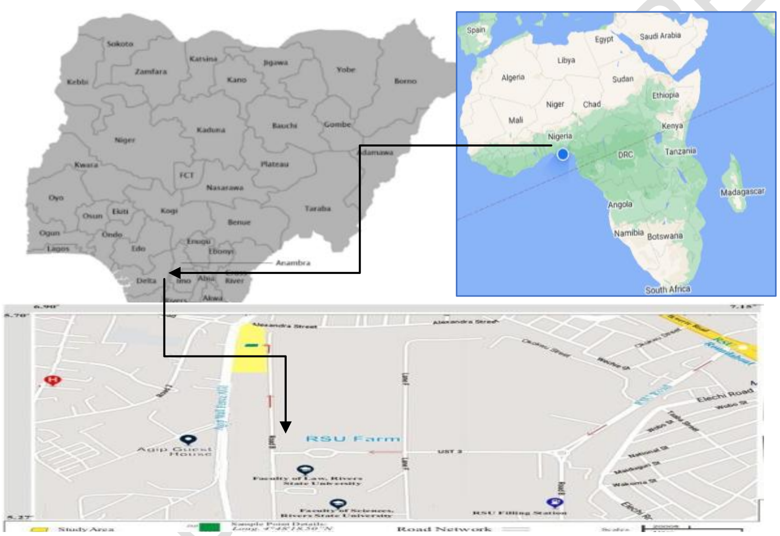

Chart 1: Map of Rivers State University indicating Demonstration Farm

Design consideration of combined weighing and non-weighing lysimeter

A cylindrical shaped design was chosen for the small scale lysimeter which consists of an inner and outer cylinder, fabricated from mild steel. The device combined the characteristics of a weighing and non-weighing lysimeter as shown in Fig 1, 2 and 3. The weighing and non-weighing lysimeter was made from readily available and locally sourced material. The cylindrical shaped device has a depth of 0.4572m with an installation depth of 0.4318m, the bottom cover of the inner and outer canister perforated with 2mm holes for easy drainage control. The facility depth as stated above is contrary to the design depth of 100 – 200mm (Obioma et al., 2015) to accommodate the rooting depth of water leaf crop at maturity. The combined weighing and non-weighing lysimeter was filled with loamy soil and 2000ml of water was irrigated to saturate the soil. The combined mass of the facility and water leaf grown on the top soil of the lysimeter (40.42kg) was measured for a period of 2 weeks. A 16GB memory size of the micro secure data (Micro SD) card was used to store data for 336 hours.

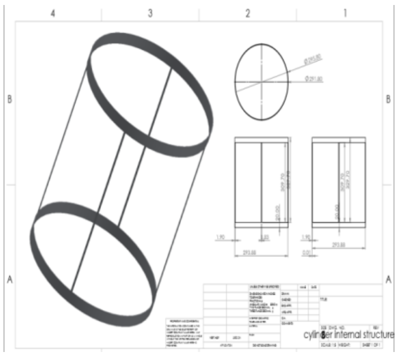

Figure 1. Internal Structure of Cylinder

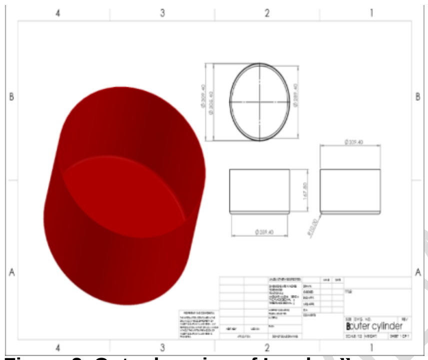

Figure 2. Outer housing of Load cell

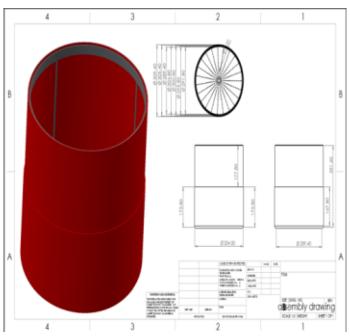

Figure 3: Combined Weighing and Non-weighing Lysimeter Assembly

Materials selection

Materials for the weighing and non-weighing lysimeter were readily available and locally sourced materials to reduce the high cost of construction Plate 1 and 2. The materials components include; mild steel, Arduino Nano, soil moisture sensor, load cell, weighing sensor module, liquid crystal display (LCD) screen, real time clock (RTC) with model DS1307, and accessories. A mild steel of 5mm thickness was used for the construction to ensure adequate strength and rigidity as shown in Plate 1.

Plate 1 and 2.Young Water LeafGrown on the Combined Weighing and Non-weighing Lysimeter2b, Water Leaf Grown on the Combined Weighing and Non-weighing Lysimeter during 2 weeks of Study

Comment [G4]: Proper labelling to be done

Arduino Nano

The size of Arduino Nano was 1.7 x 0.73 inches built on a board (ATMegat328p) as the microcontroller mounting headers for PCB application. The Arduino Nano has 8bit, 16MHz, AVR type microcontroller board that controls all other components and houses the source code that governs the operations of the system. The board comes with built-in Arduino boot loader that makes it compactable with the Arduino IDE. On the board are 14 digital input/output pins, six of which are Pulse Width Modulation (PWM) pins, eight Analog-Digital Converter (ADC) pins, an onboard 16MHz resonator, a reset button, special peripheral pins such as I^2C and SPI pins, and holes for mounting headers. The Arduino Nano requires a power supply of 5 to 12V DC with a minimum current of 500mA.

Soil Moisture Sensor

Three soil moisture sensors used in this study, uses capacitance to measure the water content of soil by measuring the dielectric permittivity of the soil. These sensors are placed at various depths in the inner canister of the lysimeter. It consists of three pins, VCC, GND and Signal, where the VCC was connected to the 5V supply pin of the Arduino Nano, GND connected to the Arduino common GND and Signal pin of the three sensors connected to Analog pins A0, A1 and A2 of the Arduino Nano. The relation between the measured property and soil moisture was calibrated considering environmental factors such as soil type, temperature, and electric conductivity.

Load cell

Resistive load cell capacity of 40kg with 5V was placed beneath the inner canister of the lysimeter which transduces the load acting on the device into an electronic signal. A known weight of soil was used to determine the resulting weight displayed on the LCD screen, logged on the SD card in an interval of 30mins. The electronic signal could be voltage change, current change or frequency change depending on the type of load cell and circuitry used. However, this study uses Resistive load cell on the principle of piezo-resistivity.

Weighing Sensor Module

The lysimeter facility was built with a 24 high precision A/D(Analog to Digital) converterwith aweighing sensor module of HX711 chips that has two analog input channels which can gain up to128 when programmed.

Liquid Crystal Display (LCD) Component

The display unit comprises of a 16x2 LCD screen and a 10K potentiometer for contrast control of the LCD. The LCD is powered by the same 5V DC used in powering the controller. Six pins of the LCD were connected to the controller, namely pins; E, RS, 11, 12, 13, 14. The LCD screen display the percentage soil moisture content and the soil weight.

Micro secured data (Micro SD) card

The adapted micro secured data (Micro SD) card on the lysimeter facility is equipped with SPI interface via the file system driver to enable interfacing, reading and writing of files through a microcontroller. The SD card can be read, logged or formatted directly from the Arduino Integrated Development Environment using the SD card library.

Real Time Clock (RTC)

The clock and calendar provides seconds, minutes, hours, day, date, month, and year information. At the end of the month, date is automatically adjusted for months with fewer than 31 days, including corrections for leap year. The clock operates in either the 24-hour or 12- hour with AM / PM indicator. The DS1307 has a built-in power-sense circuit that detects power failures and automatically switches to the backup supply. Timekeeping operation continues while the part operates from the backup supply.

3. RESULTS AND DISCUSSION

INPUT PARAMETERS

Table 1: Input Parameters

Parameter	Specification
Mass of Empty Lysimeter	12kg
Mass of Soil at Initial Filling	28.42
Moisture sensor 1 depth	100mm
Moisture sensor 2 depth	200mm
Moisture sensor 3 depth	300mm
Height of Lysimeter	355.6mm
Volume of Lysimeter	$0.02768m^3$
Diameter of inner cylinder	304.80mm
Volume of Irrigation	2000ml

Comment [G5]: Unit?

From the field experiment, data was collected on the 23rd of February and concluded on the 7th of March. Water leaf was grown on clean agricultural soil in the lysimeter measured to be 40.42kg. Graphical representation of data logged at an interval of 30mins was recorded as shown in Fig 4, 5, 6, and 7 respectively.

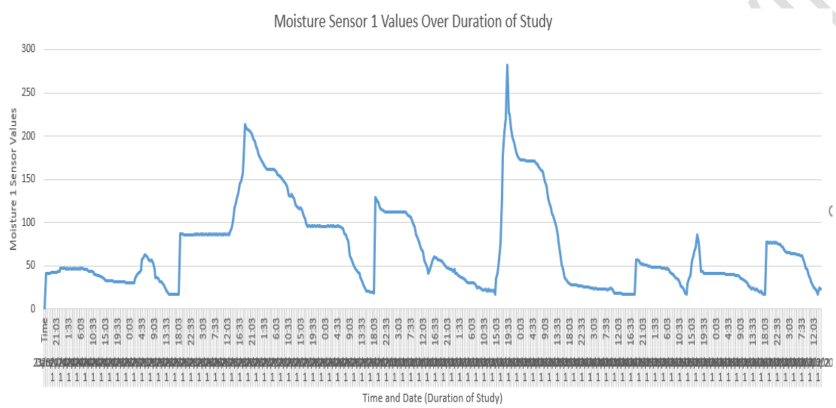

Figure 4 shows the results obtained at depth 1 over the duration of the study with three levels of soil moisture sensors found to experience various level of water retention, evaporation and transpiration. The graph shows increase in soil moisture at depth 1 over time with irrigation and rainfall that affected the root region (0 – 100mm) of water leaf may easily be affected. Despite the rainfall, there was drop in soil moisture content due to quick evaporation as a result of immediate heavy sunshine in the study area.

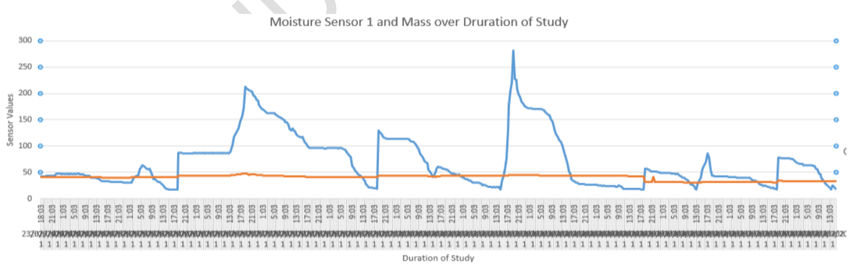

Figure 5: Moisture Sensor 1 Values and Combined Mass of Lysimeter with Soil after 2 Weeks of Study

Figure 5 shows the graphical representation of moisture sensor 1 and combined mass of the setup. The moisture content of the region experiences very high decrease due to sunlight especially between the hours of 11.03am to 14:33pm. This decrease in moisture content was observed in other levels (200mm and 300mm) except in moisture sensor 1 region with the highest moisture content data of 282. This increase was due to rainfall and not irrigation. The combined mass of the system increased by +3kg whenever irrigation was executed. The increase in mass added by rainfall was determined from the load cell unlike in the work of Tekeli et al., (2003) where recording of precipitation was done by a tipping bucket type rain gauge thus, providing results in millimetres.

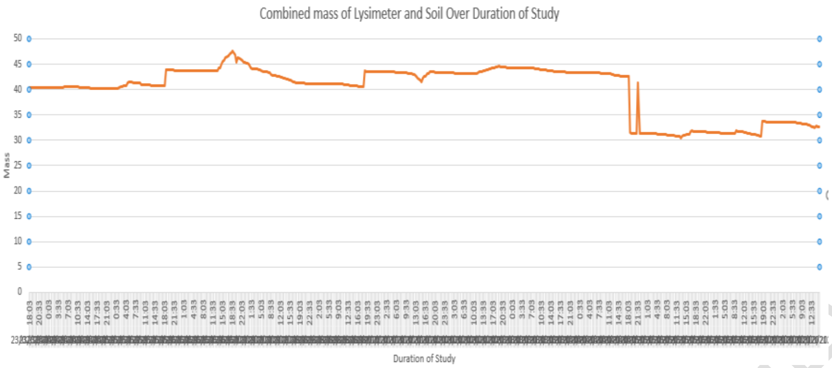

Figure6: Combined Mass of Lysimter with Soil after 2 Weeks of Study

Figure 6 shows the results obtained from the small scale lysimeter from day 1 to 2weeks with the three moisture sensor values and those of the load cell against the duration of study. Figure 7 shows the plot of three moisture sensor values and the load cell against time during the 2 weeks of study. The blue line designated on the legend signifies values and readings obtained for soil moisture 1, the peach line stands for soil moisture 2, and the grey line for soil moisture 3 while the yellow line stands for the combined mass of the lysimeter and soil during the 2weeks of study. There was increase in soil moisture with a corresponding increase in the combined mass of 46.33kg on 5 to 9 day attributed to rainfall. Hence, the combined mas of the system increase by +3kg whenever irrigation was employed as a result of a fixed volume of water (2000ml) in the setup. Draining of the lysimeter was highly effective due to the perforation of 2mm holes at the bottom of the inner cylinder. In a related work of Kohfahl et al. (2019) state that draining of the lysimeter was retarded due to reduced discharged capacity of the peristaltic pump (14ml/min) used, which was much below the maximum rate of 220ml/min indicated by the manufacturer.

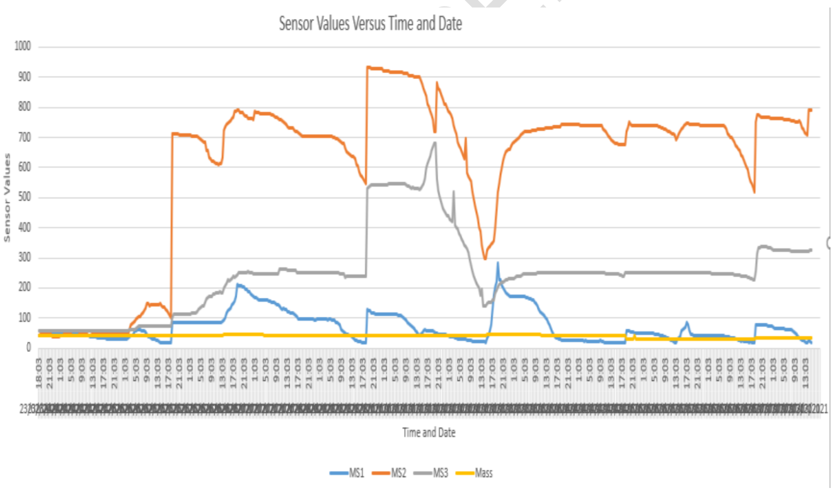

Figure 7:All Sensor Moisture Values over Time

CONCLUSION

In this work, a digital lysimeter was developed with the combined attributes of a weighing and non-weighing lysimeter. The constructed device consisted of two cylinders the inner and outer cylinder with three soil moisture sensors placed at intervals of

100mm apart with water leaf grown on clean agricultural soil placed in the lysimeter. Data logging was achieved using an Arduino Nano programmable logic controller, SD-card module, a real time clock (RTC module) and a 4GB SD card with a 16x2 LCD displaying the data. The combined mas of the system increase by +3kg whenever irrigation was employed as a result of a fixed volume of water (2000ml) in the setup. The four load cells used in the combined mass of the lysimeter were effective for consumptive use of crop.

Comment [G6]: Check the spelling

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