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DEVELOPMENT OF PHOTOVOLTAIC PROTOTYPE DEVICE FOR ESTIMATING PROJECTED LEAVES AREA

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Abstract: The aim of the current study was to developed a solar leave area meter to measure leaves area fast and accurate of Guava and Lemon leaves. As well as, validated this method by comparing it with the mechanical planimeter model Placom standard leaf area, image processing method and leaf area meter model (LI-COR, 30000A). This technique is depending on a projected area on the photovoltaic solar panel that change of the produced electric power due to the captured light. The accuracy and precision of this method were compared to that of a digital mechanical drawing planimeter method. The result indicated that the maximum accuracy percent of the area was 99.92 % and 99.60 % for using leaf area meter model (LI-COR, 30000A) and mechanical Planimater method respectively. On the other hand, the maximum accuracy percent of the area was 96.82% and 100% using a developed solar area meter and standard LiR COR instrument respectively.

Keywords: *Solar energy, Image process, Leaf area,*

INTRODUCTION

Many agricultural studies require rapid and accurate leaf area and defoliation measurements. Calculating leaf area removed as a result of insect herbivory can be useful for evaluating host plant resistance [13], pesticide activity [26], and plant-insect interactions [10]. Prior studies measuring herbivory have used visual estimates [22], hand tracings of injured [11] or a comparison of treated leaves to an appropriate control [26].

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Plant leaves condition and leaf area are an important variable within land ecosystems mainly concerning the interception of solar light and its conversion into biochemical energy. The leaf area can be measured by destructive methods based on leaf detachment planimetric, gravimetric, and non-destructive methods based on measurements or imagery calculation method, scanning method, imaging method [6]; [8]. Measuring leaf area is time-consuming and costly depending on the chosen method and/or the precision needed. Easy, rapid, accurate, non-destructive estimation of plant leaf areas offers researchers reliable and inexpensive alternatives in horticultural experiments. However, the interception of solar radiation is directly conditioned by the leaf area index (LAI) and the architecture of the plant canopy elements. Moreover, the photosynthetic process depends not only on the interception of light energy but also on the plant efficacy in its conversion into chemical energy [32]. The total leaf area of a plant is, in turn, measured or predicted by many approaches based on destructive and non-destructive methods as mentioned above. One way to use leaf area information is by the adoption of the LAI which is the relation of the leaf area with respect to the canopy projection in the soil expressed in m2/m2, [5]. Considered LAI, [19] as a biophysical variable used in global models of the climate, ecosystem productivity, biogeochemistry, hydrology, and ecology. Aligned with that, [23, 24] considered the LAI as a key variable in models related to carbon and water dynamics. There are many techniques to estimate the LAI or the total leaf area from isolated plants or a forest. The techniques based on optical approaches are the most widely adopted and developed, considering their reliability in contrast with destructive methodologies [23,24], [2], [9], which are hugely time-consuming and are quite impossible to use in large and medium plants.

An optical instrument used [2]; the LAI-2000 (LI-COR, 1992), a plant canopy analyzer, to calculate the LAI and the plant area index (PAI), considering that equipment as "one of the most commonly used optical instruments to estimate LAI by measuring the amount of diffuse radiation that infiltrates the canopy". The use of LAI is relevant to get information in small plants as pointed out by [2]; [27]; where direct methods are most feasible considering the low number of leaves. Authors,[28], evaluated the LAI-2000 (LI-COR, 1992) to obtain the leaf area index in a paddy-rice (*Oryza sativa L.*) crop, and accounted for the saturation problems presented in the results related to the low density of the rice canopy. Authors [29], the use of hemispherical photography to present an optical alternative to predict the LAI of olive trees in contrast to direct methods with total defoliation of the plants. Hemispherical photography was also presented by [14] as an optical alternative to get the LAI. The adoption of optical approaches in medium-size crop plants, up to our knowledge, are rare in the literature, and the few accounts observed, such as the work of [30], used commercial equipment with a modest amount of data, and without any possibility to get favourable statistical treatment of the large variability usually observed in these sort of indirect analysis. The area of a leaf can be obtained by indirect, non-destructive methods, such as mathematical models or equations that estimate, with reasonable accuracy, leaf area as a function of linear dimensions (such as length, width and/or the product of both).

The ease and speed of execution and low cost are important (independent of modern, expensive equipment) because these methods do not destroy the plant, and this allows measurements to be made several times on the same individual sample [20], [1], [17], [15].

Recent research was conducted to develop equations that relate the diminutions of the leaf to the leaf area of some fruit trees, such as passion fruit [18], mango [15], apple [4], acerola [16] and vines [3], with a high degree of accuracy.

However, there are no reports on the estimation of leaf area in guava, and for this fruit, leaf area could be an important tool for assessing growth, productivity and phytosanitary treatments.

The Lemon (*Citrus Limon*) is a species of a small evergreen tree in the flowering plant family and is produced in Egypt in a large area. In Egypt Guava (*Psidium guajava. L*) occupies about 38000 feddan, yielded about 314000 tons as annual fruit production with an exported range about 1631238 metric tons to many countries [12]. Since the 1950s, guavas – particularly the leaves – have been studied for their constituents, potential biological properties, and history in folk medicine [31]

Objectives: The aim of this paper was to develop an accurate solar leaf area meter. As well as comparing two measuring instruments to determine the highest accuracy. We validated this method by comparing the results with the mechanical planimeter model Placom standard leaf area, image processing method and leaf area meter model (LI-COR, 30000A).

MATERIAL AND METHODS

Mechanical method

The Roller-Type Electronic Digital Planimeter made by Placom is an instrument was used to measure the surface area of an arbitrary two-dimensional shape. This method was used and recommended by [19].

Imaging process method

The software ImageJ V1.52 and digital camera Cannon ™ Powershot 45S was used to estimate the leaves area. ImageJ is a public domain Java image processing program inspired by the National Institutes of Health U.S.A. The ImageJ program can calculate area and pixel value statistics of user-defined selections. It can measure distances and angles. All analysis and processing functions are available at any magnification factor. ImageJ was designed with an open architecture that provides extensibility via Java plug-in. With the object outlined, the surface area was calculated by selecting the measure option [19].

Standard Commercial equipment Leaf Area Meter

Commercial equipment LAI-3000 (LI-COR, 30000A) in Sacha research station and all the data assembled were validated using a destructive method, considered as a standard. Thirty mature plants of Guava and Lemon crop were observed with direct and indirect methods, and models were proposed comparing with the actual leaf area from the Leaf Area Meter (Li-COR Li30000A) which has been shown to have a precision of 99% (LI-COR, 2006) compared with total defoliation measurement.

Developed solar leaves area device

The solar leaves area device consists of a black box made from PVC opened from the bottom side and fixed in the internal top side 15 LED lamp connected in three rows as the source of light that projected on the solar panel photovoltaic in bottom side. The bottom side of the black box was jointed with a small photovoltaic model Mono-crystalline silicon 18V, 36W no-load voltage 18-23VDC and Load voltage 18V to obtain the dark box inside, as well as it is connected in the electrical circuit. The block 9 Volte dry battery was used and connected with the switch as the power source of the 15 LED lamps. The electricity circuit of the device was presented as shown in figure1. The Tektronix Oscilloscope Model TPS 2024 and digital multi-meter 345 were used to measure the output voltages from the solar panel photovoltaic under different tests conditions. The two different measuring instruments were compared to know the accuracy of the developed solar leave device area meter as shown in figure 2.

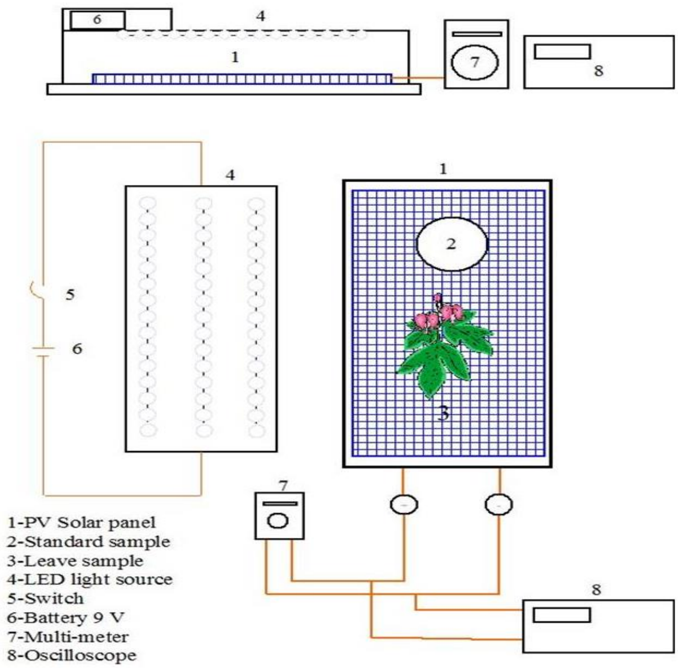

Fig.1. The components and the electrical circuit of the developed solar leaves area meter

Experimental design and data analysis

The accuracy and precision of leaf area estimates were compared from the different methods: developed solar panel leaves area device, imaging process integrated with imageJ V1.52 software, and camera, mechanical method estimates from the planimeter with portable area meter model Li-COR Li30000A.

Three separate tests were conducted using circle filter paper cards Macherey Nagel, (MN) with known area 4 cm diameter (12.56 cm^2), a single leaf, and multiple leaves. In the first test, one, two and four MN were used to evaluate the precision as shown in figure 3. The different trails test of both instruments oscilloscope and multi-meter to obtain a high accuracy were used to estimate a known area of MN (12.56, 25.12 and 50.24 cm^2). every trial was scanned three times with the Planimeter and the digital camera and area meter model Li-COR Li30000A. Descriptive statistics were used to compare the accuracy (mean) and precision (standard error of the mean, SEM) of each method.

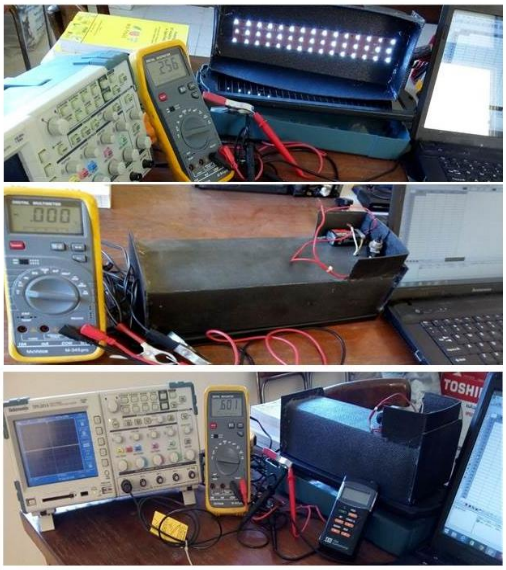

Fig.2. The developed solar leaf area meter and the instruments to measure the power and voltage

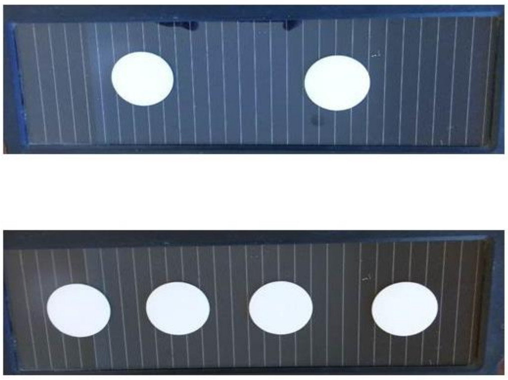

Fig. 3. The standard filter paper (Macherey Nagel, MN 4 cm diameter)
and solar panel to measure the accuracy of leaf area.

Assuming the solar cell panel with an average 10% and that average of solar energy measured by solar power meter and recorded reaches the panel was w/m2 .The following equation was used to estimate the Leaves area.

Where is:

$P_{1\ available}$= P* eff.* A_o……………………………………………… (1)

A_o projected area of standard panel

P measured solar output power in the device, W/m^2

$P_{2\ available}$= P* eff.* A_1……………………………………………… (2)

A_1 projected area of the panel when measured the leaf, cm^2

P_2 measured output solar power in the device, (W)

Leaf area= (P_1* $A_{o\ solar\ panel}$ -P_2* $A_{o\ solar\ panel}$)/X_1……………..…….. .(3)

= $A_{o\ solar\ panel}$ * ((P_1 -P_2)/P_1………………………………..... (4)

The current output was measured; it was constant value 3 A (ampere) from the panel then the leaf area could be calculated as:

Leaf area = $A_{o\ solar\ panel}$ * (V_1 -V_2)/V_1…………………………..…… (5)

Where as:

V_1 voltages output at $A_{o\ solar\ panel}$, (V)

V_2 voltages output at $A_{1\ solar\ panel}$, (V)

RESULTS AND DISCUSSION

The result of the current research presented that the different tests to find the leaf area by using a developed solar panel leaves area compared with three different leaves area methods.

Calibration of a developed solar area meter

Table 1 indicates the measured values of output voltages from the solar panel by two different instruments under different conditions. The formula (4) used to estimate the leaf area by subtracting the values from table 1. To determine the accuracy of the developed solar area meter, the standard MN were used in with five replicates to measure the output voltages and after that estimating the area using equation (4) due to the change of the solar panel projected area.

Table 1. The output voltages values from the solar panel by using two different instruments under different conditions

Trail		Output voltages V					
		1 card		2 card		4 card	
		Osci.	Multi-meter	Osci.	Multi-meter	Osci.	Multi-meter
P2		8.54	8.58	8.35	8.29	7.53	7.47
		8.52	8.57	8.13	8.08	7.31	7.26
		8.53	8.51	8.13	8.12	7.32	7.30
		8.53	8.59	8.03	8.11	7.24	7.18
Av		8.53	8.57	8.13	8.08	7.31	7.26
P1		8.93	8.89	8.93	8.89	8.93	8.89
		8.93	8.89	8.93	8.89	8.93	8.89
		8.93	8.89	8.93	8.89	8.93	8.89
		8.93	8.89	8.93	8.89	8.93	8.89
Av		8.93	8.89	8.93	8.89	8.93	8.89

After testing the accuracy of a developed solar leaves area meter by using the standard know areas MN, a developed solar leaves area used to measure the leaves area for both *Citrus Limon* and *Psidium guajava. L*, three leaves from guava trees and lemon were collected and measured by different methods developed solar leaves area device, imaging process software, mechanical method planimeter and area meter model Li-COR Li30000A.

Fig. 4: Portable area meter model Li-COR Li30000A measured the area of lemon (*Citrus Limon*) and guavas (*Psidium guajava. L*)

The first test result of the calibration a developed solar area meter indicated that the using of oscilloscope compatible with solar panel gave a high accuracy value of leaves area for standard know area (filter papers). Table 2 indicated that the estimated area values by using two different instruments compared with standard MN under different conditions. Using the multi-meter with a developed solar panel gave low accuracy values of leaves compared to oscilloscope instrument. The average values of standard MN were 12.10 cm^2, 23.57cm^2 and 47.58 cm^2 for oscilloscope compared with 10.03 cm^2, 23.08 cm^2 and 47.58 cm^2 using the multi-meter.

The oscilloscope combined with solar panel recorded -4.8% area differences in al trials compared with -10.9% in the case of using the multi-meter. It is recommended to use a highly accurate instrument to measure the output power in developed solar area meter. It will guarantee better results and reliability calculating leaves area.

Table 2. The estimated area values by using two different instruments compared with standard filter papers (MN)

Trails	Filter papers area, cm^2					
	1 card		2 card		4 card	
	Osci.	Multi-meter	Osci.	Multi-meter	Osci.	Multi-meter
1	11.76	9.43	21.51	18.22	42.39	43.13
2	12.33	9.74	24.13	24.60	48.92	49.51
3	12.22	11.54	24.01	23.39	48.79	48.29
4	12.31	9.72	24.10	24.61	48.91	49.50
5	12.30	9.70	24.12	24.58	48.90	49.49
Ava.	12.10	10.03	23.57	23.08	47.58	47.98
Ac.area	12.56	12.56	25.12	25.12	50.24	50.24
Differ. %	-3.0	-20.2	-6.2	-8.1	-5.3	-4.5

The second test result of the calibration a developed solar area meter indicated that the using of oscilloscope combined with a developed solar area may be made a competition with the mechanical planimeter, image processing and leaf area meter model (LI-COR, 30000A) for the standard MN. Figure (3) indicated that the test area values by using different leaves area methods compared with the actual area for standard filter papers. The mechanical planimeter and leaf area meter model (LI-COR, 30000A) gave the highest accuracy to measure the known area of MN compared to the image processing method and a developed solar area meter. The area for 1, 2 and 4 MN were 12.50, 25.10, 50.44 cm^2 for using leaf area meter model (LI-COR, 30000A) compared with 12.10, 23.88, 48.70 cm^2 for using a developed solar area meter. The maximum accuracy percent of the area was 99.92 % and 99.60 for using leaf area meter model (LI-COR, 30000A) and mechanical Planimater method respectively. On the other hand, the maximum accuracy percent of the area was 96.34 for using a developed solar area meter as shown in figure 5 and table 3. A developed solar area meter may be able to apply as leaves area meter and it is not expansive compared with leaf area meter model (LI-COR, 30000A) and mechanical Planimater methods.

Table 3. Present the accuracy percent of different methods to measure the areas for standard filter cards.

Leaf area methods	Area, cm^2			Accuracy percent of area, %			
	1 MN	2 MN	4 MN	1 MN	2 MN	4 MN	LSD
Ac. area	12.56	25.12	50.64	100	100	100	0.24
Solar devl.	12.10	23.88	48.70	96.34	95.06	96.17	0.24
Li-COR	12.50	25.10	50.44	99.52	99.92	99.61	0.24
Image	12.06	24.72	49.34	96.02	98.41	97.43	0.24
Plani.	12.46	25.02	50.24	99.20	99.60	99.21	0.24

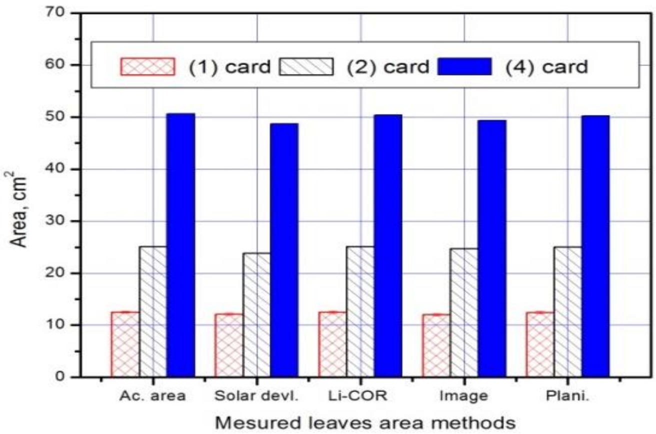

Fig 5: The test area values by using different leaves area methods compared with the actual area for standard filter papers.

Evaluation of a developed solar leaves area device

From the above results and tests, a developed solar leaves area device used to measure the leaves area for *Citrus Limon and Psidium guajava*. L. As well as, comparing the leaves area values measured by the developed device with Li-COR leaves area meter, imaging processing and mechanical planimeter method. Figure 6 illustrates the comparison between laves area methods planimeter, image processing, standard LiR COR instrument and a developed photovoltaic leaves area meter device for Guava and Lemon leaves. The leaves area of Guava and Lemon was 38.9 cm^2 and 14.17 cm^2 respectively by using the standard LiR COR instrument. The leaf area of Guava and Lemon was 37.66 cm^2 and 13.49 cm^2 respectively using a developed photovoltaic leaves area meter device comparing with 38.84 cm^2 and 13.67 cm^2 using image processing method as shown in figure 5 and table 4. The accuracy percent of the area of standard LiR COR instrument was used as a 100 % standard for leaf area of both plants. The accuracy percent of area of a developed photovoltaic leaves area meter device was 96.82% and 95.20 % for leaf area of Guava and Lemon respectively as shown in table 4. The developed device may be able to measure the leaf area of the plant with accuracy of 96.82%.

Table 4: Display the leaf area of Guava and Lemon using different Leaves area methods

Plant	Leaf area, cm^2				Accuracy percent of area, %			
	Li-COR	Plani-meter	Image Proc.	Solar Dev.	Li-COR	Plani-meter	Image Proc.	Solar Dev.
Guava	38.65	38.74	38.84	37.66	100.0	99.60	99.85	96.82
Lemmon	14.14	14.06	13.67	13.49	100.0	99.25	96.47	95.20

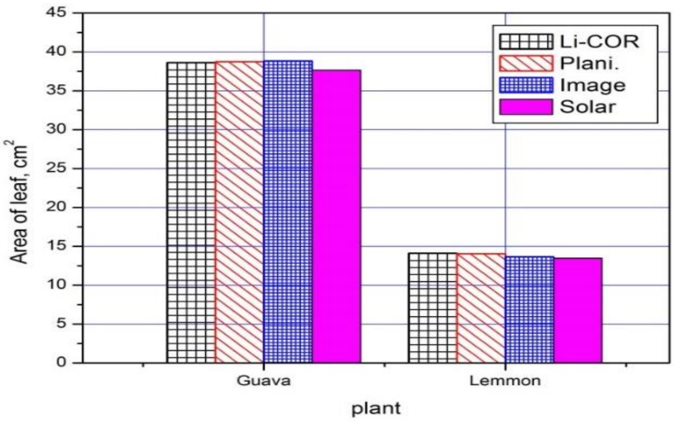

Fig. 6: The difference between laves area methods planimeter, image processing, and standard LiR COR instrument compared with developed photovoltaic leaves area meter for Guava and Lemon leaves.

CONCLUSIONS

The following conclusions are drawn from this investigation on developing the solar PV Planimeter. It is recommended to use a highly accurate instrument to measure the output power in developed solar area meter. It will guarantee better results and reliability calculating leaves area. The developed solar area meter able to estimate leaves area, offering accurate, rapid, and reliable method. It is not expansive compared with leaf area meter model (LI-COR, 30000A) and mechanical Planimeter methods. The developed device may be able to measure the leaf area of the plant with an accuracy of 96.82%. It is recommended to start of fabrication of the solar device leaf area meter; the device then should be integrated with high accuracy short electricity circuit for measuring the voltage and programing it to calculate the leaves area directly.

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RAZVOJ FOTONAPONSKOG PROTOTIPA UREĐAJA ZA PROCENU PROJEKTOVANJA POVRŠINE LIŠĆA

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Apstrakt: Cilj ove studije je razvoj solarnog uređaja za meranje površine lišća za brzo i precizno određivanje površine listova za Guavu (*Psidium guajava L*) i Limun (*Citrus Limon*).

Metoda je potvrđena upoređenjem sa modelom mehaničkog planimetra Placom standard kod određeivanja površine lista, metodom obrade slike i modelom merenja površine lista (LI-COR, 30000A).
Ova tehnika zavisi od veličine površine na fotonaponskom solarnom panelu koja izaziva promenu proizvedenog (indukovanog) električnog impulsa, zbog usmerenja svetlosti prema površini lista.
Tačnost i preciznost ove digitalne metode je upoređena sa metodom mehaničkog planimetra Placom standard.
Rezultat je pokazao da je najveći procenat tačnosti metode izmerene površine od 99,92 % i 99,60 % kod korišćenja modela LI-COR, 30000A, u odnosu na metod Mehaničkog planimetara, respektivno
Sa druge strane, najveći procenat tačnosti određivanja površine lista je 96,82% i 100% korišćenjem razvijenog solarnog tipa planimetra u odnosu na standardni LiR COR instrumenta, respektivno .

Ključne reči: *Solarna energija, procesiranje slike, površina lista*

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