



Digital Image Processing Approach for Determination of Leaf Area of Field Crops

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Abstract: A digital image processing method has been developed to estimate the leaf area of clusterbean using commonly available printer-cum-scanner in a desktop computer. In this method, leaves were collected from the field and scanned in the laboratory over a transparent sheet placed on the top glass cover of the scanner bed. Further, the scanned image was processed through a programming code to compute the leaf area. A comparison of digital method with grid method revealed that the leaf area was slightly lower in grid method than in digital method because in the digital method minute details of leaf area could be accommodated whereas in grid method it was not. The digital method could be more suitable for crops with small leaves where the grid method is tedious. In future, smart phone based android application may be developed to capture the photographs of the leaves in the field and analysed subsequently to obtain the area. The quick assessment of leaf area using digital method may aid in timely management of water and nutrients in the field.

Key words: Leaf area index, digital image processing, grid method, clusterbean.

Leaf area of crops is an important parameter to determine photosynthesis and transpiration rates and thus leaf area index (LAI) is often considered as a key factor to assess crop growth and bio-productivity (Mohsenin, 1986). Knowledge on leaf area is also important to decide the right amount of application of fungicide and insecticide to protect the crops from pests and diseases (Suggs *et al.*, 1960). Therefore, for both plant scientist as well for process engineers, measurement of accurate leaf area quickly in the field is a great concern, more specifically for those plants in which leaves are the major commercial products e.g. tobacco, tea or green leafy vegetables (Raper *et al.*, 1974, Igathinathane *et al.*, 2006).

Leaf area of field crops is commonly measured through direct methods whereas for plant species with large canopy (e.g. forest trees, shrubs etc.), indirect methods are most common. Direct methods to determine leaf area are accurate but destructive, costly and time consuming. Most common direct method is the scanning of leaves by using leaf area meter, but the process is costly and time consuming. The indirect methods such as utilisation of predictive models require measurement of leaf area through direct methods for its calibration (Gamiely *et al.*, 1991; Godoy *et al.*,

2007; Carvalho *et al.*, 2017). A comprehensive detail of different methodologies for leaf area measurement is available in Sestak *et al.* (1971).

During past few years, rapid advancement has taken place in machine learning techniques and digital image processing approaches. The digital image analysis is fast, accurate and reproducible compared to the labor- and time-intensive grid (counting) method. The image analysis of a leaf allows the estimation of area including both healthy and damaged leaflets (Adami *et al.*, 2008). Keeping these in mind, it was aimed to develop a simple method employing the digital image processing technique in this study with clusterbean as a test crop.

Materials and Methods

Field experiment details

Clusterbean crops were grown at experimental farm of ICAR-Central Arid Zone Research Institute (ICAR-CAZRI), Jodhpur, Rajasthan. Several accessions/varieties of the crop (Table 1) were grown in the trial and sowing was done on 6th July 2019 with a row to row distance of 50 cm. Observations on leaf area, plant density and other growth parameters of the crop were recorded in triplicate in three blocks starting from 17 days after sowing (DAS) till the harvest. More specifically, observation

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Table 1. Plant growth parameters of clusterbean accession/varieties measured during kharif season of 2019 at Jodhpur, Rajasthan

Date	Clusterbean accessions/varieties	Number of leaves per plant	Number of plants per m ²
29 July, 2019	CAZG 16-1-1, CAZG 17-3-1, CAZG 17-3-2	14±1	27±1
5 August, 2019	RGC 1033, CAZG 16-19, HG 2-20	21±3	27±1
13 August, 2019	CAZG 17-16-1, CAZG 17-19-1, CAZG 17-20-1	39±13	31±4
19 August, 2019	CAZG 17-16-1, CAZG 17-19-1, CAZG 17-20-1	49±7	27±2
26 August, 2019	RGC 1033, CAZG 16-19, CAZG 17-3-1	78±10	27±4
2 September, 2019	CAZG 17-4-2, CAZG 17-18, RGC 1033	125±9	31±5
9 September, 2019	CAZG 16-9, HG 2-20, RGC 1038	251±17	19±1
17 September, 2019	CAZG 17-4-2, CAZG 17-19-4, CAZG 17-19-2	67±10	31±5
23 September, 2019	CAZG 16-9, HG 2-20, RGC 1038	53±11	22±3
30 September, 2019	CAZG 17-4-3, CAZG 17-19-1, CAZG 17-20-1	29±1	25±3
9 October, 2019	CAZG 16-12-2, CAZG 17-3-2, CAZG 16-17	69±39	25±6

parameters included number of leaves per plant, number of plants per meter of crop row, area of three selected leaves of three different sizes from a plant. Three categories of selected leaves: small size (from the top), middle size (from the middle height) and the big size l(from the bottom) were collected, and brought to laboratory to measure the leaf area using both grid method and digital method.

Measurement of leaf area

Collected leaves were placed over a gridded transparent sheet (grid size = 1 cm) and scanned using a commonly available printer-cum-scanner-cum-photocopier (Model HP Laser Jet

M1005 MFP) attached with a desktop computer. Transparent sheet was placed on the top glass cover of the scanner to ensure protection of glass cover of the scanner and leaves were kept on the sheet. The image was captured in RGB color mode with a resolution of 300 dpi (dots per inch).

Grid methods for calculation of leaf area: In the grid method, the printed versions of the scanned image of leaves were used to calculate the leaf area. Number of grids covered by leaf was counted and then cumulated to obtain the total leaf area (Fig. 1). During counting of grids, four types of grids were considered and these were fully covered grid, three-fourth covered

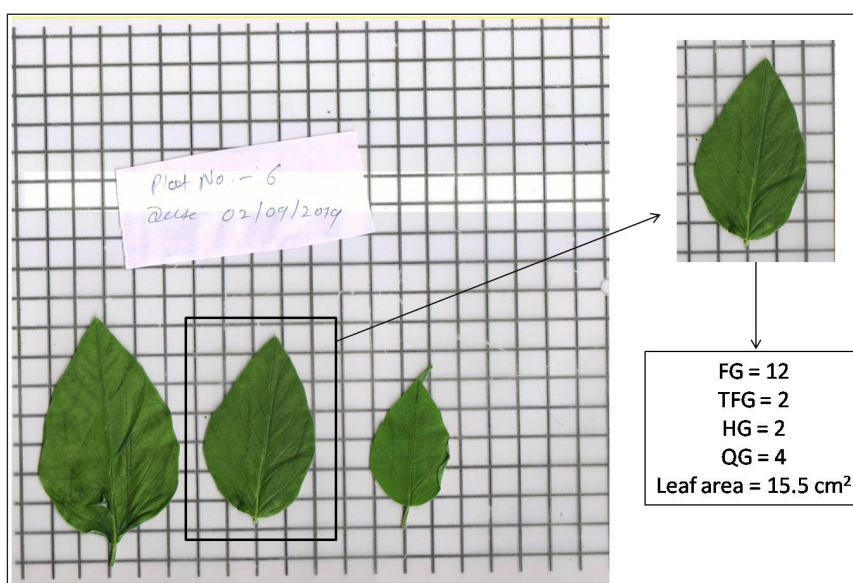


Fig. 1. Grid method of leaf area calculation.

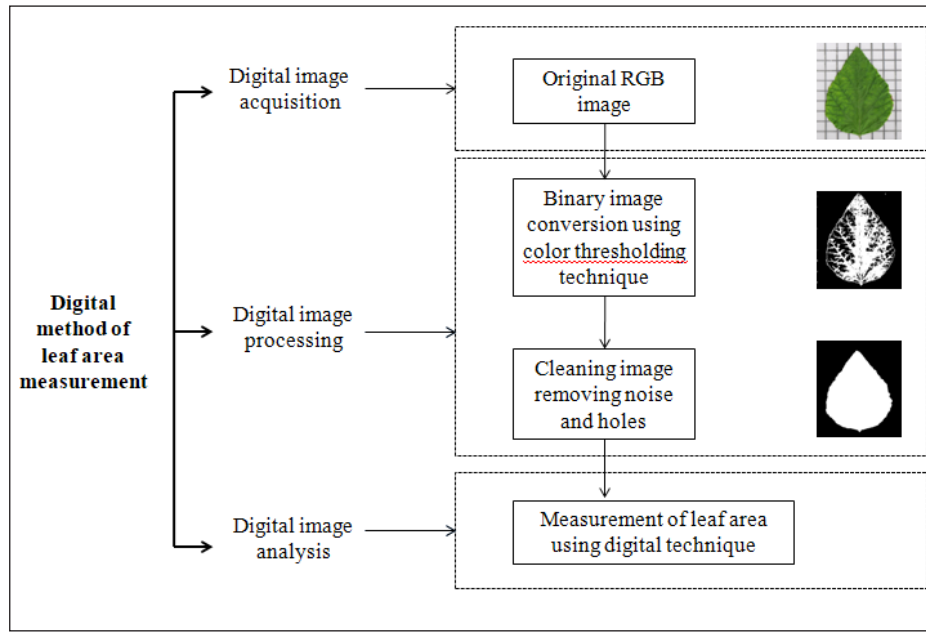


Fig. 2. Digital method of leaf area calculation.

grid, half-filled covered grid and quarter-filled covered grid. Area covered less than quarter of a grid was either neglected or aggregated with such type of neighbor grid to obtain an approximate quarter grid. Total leaf area was calculated as:

$$LA_{grid} = FG + (TFG \times 3/4) + (HG/2) + (QG/4) \quad \dots 1$$

where, LA_{grid} is leaf area based on grid method (cm^2), FG is the number of fully covered grids, TFG is the number of three-fourth covered grid, HG is the number of half-filled covered grids and QG is the number of quarter filled grids.

Digital method of calculation of leaf area:
A detailed procedure to compute leaf area using scanned image is given in Fig. 2. Image processing codes were written in MATLAB R2018a to follow the stepwise procedure of obtaining the final area (Fig. 3). To isolate the object from its background, the RGB color image was converted into $L^*a^*b^*$ image. Color thresholding technique was used to convert the image into a binary image. The threshold value was identified based on the experiment for different leaves and background color. The noise and holes of binary images were filled by morphological opening and closing. Leaves were represented by 1 (white) and the background by 0 (black), so the number of white pixels (leaf area) adjacent to each other represented the leaf area (Fig. 2). The

values are in pixel which can be converted into understandable form using following equation.

$$LA_{digital} = \text{Number of pixels represented as leaf} \times \text{area of a pixel} \quad \dots 2$$

where, $LA_{digital}$ is the Leaf area (mm^2) calculated through digital method. In case of 300 dpi

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%% Matlab code to Measure the leaf area
close all; clear all; clc; warning off;

% Opens a modal dialog box to import the image from current folder
FileName = uigetfile('*.jpeg;*.jpg', 'Pick a jpg file');

RGB_Image = imread(FileName);

%% Convert RGB image to lab image for color thresholding
I = rgb2lab(RGB_Image);

% Define thresholds for 'L' value' based on histogram settings
channel1Min = 0;
channel1Max = 100;

% Define thresholds for 'a' value' based on histogram settings
channel2Min = -31;
channel2Max = -6;

% Define thresholds for 'b' value' based on histogram settings
channel3Min = -60;
channel3Max = 61;

% Create mask based on chosen histogram thresholds
Binary_Image = (I(:,1,1) >= channel1Min) & (I(:,1,1) <= channel1Max) & ...
(I(:,1,2) >= channel2Min) & (I(:,1,2) <= channel2Max) & ...
(I(:,1,3) >= channel3Min) & (I(:,1,3) <= channel3Max);

%% Image processing to clean the noise and holes
Leaf_Binary_Image = bwareaopen(Binary_Image, 10000);
filled_Image = imfill(Leaf_Binary_Image, 'holes');

%% Display RGB and binary processed Image
figure;
subplot(1,2,1), imshow(RGB_Image);
subplot(1,2,2), imshow(filled_Image);

%% Measurement of Leaf Area
Stats = regionprops('table', filled_Image, 'Area');

DPI = 300; % for 300 dpi Image
p = DPI/25.4;

Area = (1/(p^2)) * (Stats.Area);

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Fig. 3. MATLAB code for calculating leaf area using digital image processing.

image, area of a pixel was 0.00718 mm² considering the presence of 90,000 pixels in 1'×1' image area.

The MATLAB code for computing the leaf area using digital method is given in Fig. 3.

Calculation of leaf area index: Leaf area index (LAI) of clusterbean crop was calculated from the measured leaf area of each category of leaves (small, medium and large) during each measurement period as follows:

$$LAI = \frac{\text{Total leaf area (mm}^2\text{)}}{\text{Total ground area (mm}^2\text{)}} \quad \dots 3$$

Total leaf area in plants within 1 m × 1 m ground area was calculated by multiplying the average leaf area with number of leaves in a plant and then further multiplying it with total number of plants in 1 m × 1 m area.

Results and Discussion

Variation of leaf area during crop growth season of clusterbean

Number of leaves per plant after 24 days of sowing (DAS) was 14±1 whereas it reached to the highest of 251±17 on 66 DAS (Table 1). Average plant density was 26 m⁻² although it varied across observation periods, which was mainly due to different accessions/ varieties during each observation period in the experimental plot (refer Table 1).

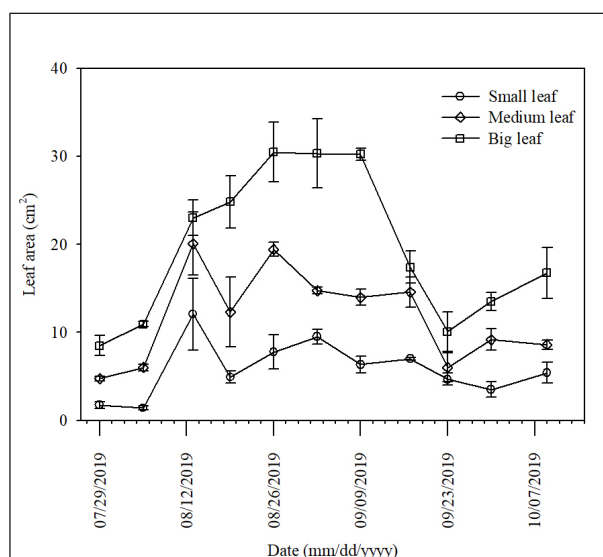


Fig. 4. Variation of leaf area of clusterbean measured through digital method during kharif season of 2019 at Jodhpur, Rajasthan.

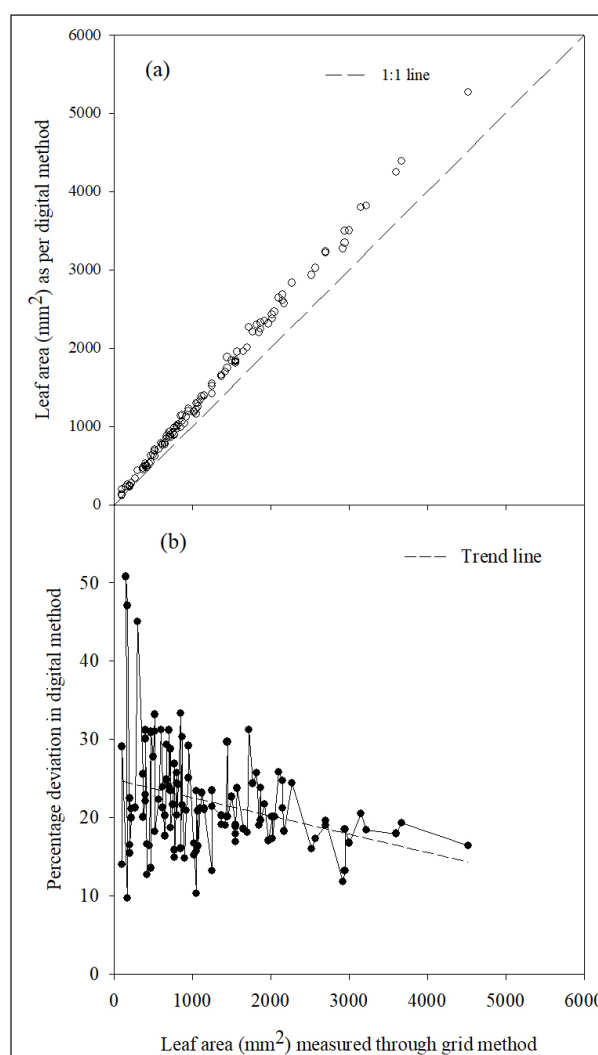


Fig. 5. Comparison of grid method and digital method for measurement of leaf area of clusterbean, (a) scatter plot of leaf area measured through grid method and digital method and (b) percentage deviation in leaf area measured through digital method over grid method.

Average area of small sized leaves varied from 1 to 12 cm² whereas for medium sized and big sized leaves it varied from 4 to 20 cm² and from 8 to 30 cm², respectively. Average area of a leaf of clusterbean crop on 17 DAS was lowest (4.61 cm²) whereas it was highest (19.22 cm²) on 52 DAS.

Comparison of digital approach and grid method

The 1:1 comparison plot between leaf area measured through grid method and the same through digital method revealed that with increase in leaf area, difference becomes larger (Fig. 5). This is due to the fact that in

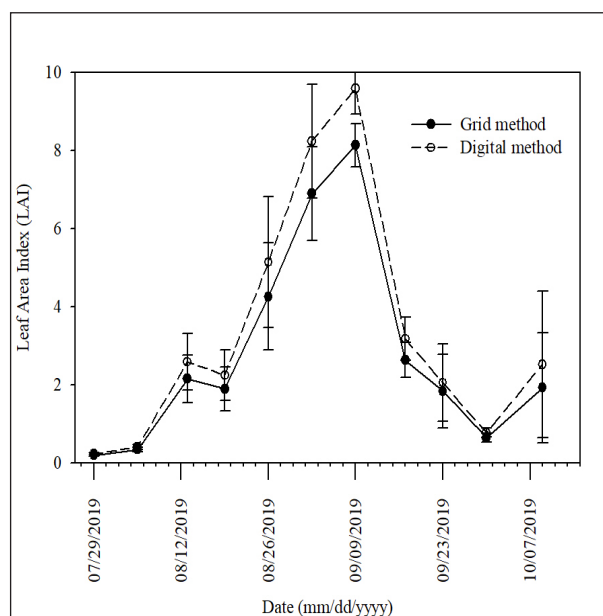


Fig. 6. Leaf area index of clusterbean crop grown at Jodhpur, Rajasthan during kharif season of 2019.

the grid method, the portion of area covered by a leaf $< 1 \text{ cm}^2$ grid area was approximated as either half grid or quarter grid to count the total number of unit grids covered by the leaf for final computation of total leaf area. In the digital method, the size of unit grid, which is often referred as pixel, was 0.007 mm^2 with 300 dpi pixel resolution. Therefore, minute details of leaf area could be accounted, which resulted in comparatively higher leaf area in digital method than in grid method.

Per cent deviation of measured leaf area in digital method over grid method was always positive. With increase in leaf area, the per cent deviation decreases. It indicates comparatively lower leaf area measured through grid method than through digital method. Further, such lower leaf area in grid method was more pronounced when the leaf size was small. For small sized leaves, the minute details of leaf area could be counted using digital method, which was otherwise very tedious through grid method.

Leaf area index (LAI) of clusterbean crop measured using both digital and grid methods is presented in Fig. 6. Initially, the LAI was 0.2-0.4 up to 30 DAS. The highest values of LAI was recorded on 66 DAS, which were 8.14 in grid method and 9.59 in digital method. Differences were evident during the middle stage of crop growth. Therefore, it may be concluded that

using digital method, it is possible to quickly and precisely measure LAI of field crops as compared to conventional grid method.

Conclusion

Digital method of leaf area calculation was developed in this study which was compared with conventional grid method. Grid method always resulted in 20% lower LAI in clusterbean than digital method. It is because in the grid method very minute areas of irregular shaped leaves could not be accommodated in manual grid method, whereas in digital method it was included in the form of high resolution digital image. The digital method was also found very suitable for rapid calculation of leaf area index even in field condition. With the abundant use of smart phones at present time, it may be feasible to scan the leaf in the field itself using a smart phone camera and a reference sheet followed by digital image analysis using a suitable android application. Therefore, rapid assessment of plant growth in field condition is possible through digital leaf area assessment which may help in timely adoption of suitable crop management practices.

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