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Estimation of Leaf Area and Leaf Area Density for Design Optimization of a Recycling Tunnel Sprayer

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A tunnel sprayer system is considered as one of the most economical and reasonable sprayers for protection of an orchard crop. The performance of the spraying system (spray deposition %, recycling %, and deposition % on abaxial and adaxial surface) could be improved through appropriate design. However, the morphological parameter of the orchard significantly influenced accuracy and effectiveness of the same spraying system. Therefore, this study was conducted to determine the morphological parameters of guava tree. Three techniques were used for estimation of leaf area: Grid Count Method (GCM), Image Processing Technique (IPT) and Regression Model (RM). The grid count method was used as a reference for area estimation. R^2 was 0.98 and 0.94 for IP & RM compared to GCM, respectively. In the regression model, only length and width of the guava leaf were found statistically significant ($P < 0.01$). It was concluded that the image processing technique provided better results for leaf area estimation with mean error ± standard deviation (−0.23 ± 3.41) than regression developed model. This study ensured the accuracy of image processing technique for the leaf area estimation and allows the researchers to deal with voluminous of leafs with accurate and quick response. Leaf area density (LAD) was recorded to be in range of 0.07–2.73 m^2/m^3. These morphological parameters could be used for design optimization of recycling tunnel sprayer in future, which would help to improve the performance of tunnel system.

Keywords: Canopy, Grid count method, Image processing, Regression model

Introduction

Chemical method is most preferred and widely adopted technique for the handling pests on large scale. Various plant protection equipments namely knapsack sprayer, mist blowers dusters, boom sprayer etc. has been developed to dispense chemical on plant canopy. However, application through existing equipment has resulted in wastage of chemicals in soil water ecosystem indirectly deteriorating the environment. Plant protection especially in horticultural crops is a very challenging task considering its commercial importance, varied canopy size, density and canopy configuration. Moreover, intense pest infestation at adaxial (lower) surface of leaf has forced the farmers to apply chemical through air assisted sprayers for improved transfer, deposition and distribution of the spray droplets on plant leaf surface.

Various plant protection equipments have been developed globally to cover varied plant canopy and density of horticultural crops. Tunnel spraying system is one of such technologies where the part of applied chemical solution is recycled again in the spray tank preventing the leakage of chemical in the environment. The number of studies has confirmed the remarkable recycling rate percentage of the tunnel spraying system in different crops.[1–8] The potency of tunnel sprayer is expressed in terms of recycling rate, penetration of droplets, deposition ($\mu l/cm^2$) and % coverage.

Morphological parameters of plant canopy directly affect the behavior of spray droplets on plant surface. Leaf surface area and leaf area density significantly influence the deposition and penetration of spray droplets on plant canopy. Moreover, uniform distribution of spray droplets is directly associated with mortality of pest measured in L50 and L90 dosage. Along with spray deposition, penetration and pesticide application rates are generally affected by canopy characteristics, like, Leaf Area Index (LAI) and Leaf Area Density (LAD). Research around the globe has established that higher LAD has resulted in more uniform spray distribution and lower droplet density at higher air velocity of sprayers. The large leaf area and leaf area density reduce the penetration and deposition of the droplets.[9–11] So, there is a pre-requisite for the accurate measurement of the leaf area and leaf area density.

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Henceforth, estimation of LAI and LAD is an important to estimate the application rate, droplet density, droplet deposition and % coverage for a given plant geometry and configuration. LAI and LAD are function of leaf surface area which indirectly determines the design and operational parameters of the plant protection equipments. Several techniques have been used for the estimation of the leaf area viz. standard grid count method, regression model, leaf area meter, image processing technique etc. The standard grid count method is used as a reference in most of the case due to the highest accuracy, but it is very laborious and time consuming method. The regression equation technique has a capability to overcome the problems of the standard grid count method. However, it fails to accommodate all kind of the leaves due to the variation in ratio of the length and width of the leaf. Therefore, an attempt has been made to use regression model and image processing technique for leaf area determination and compare it with grid count method of leaf area determination. This work will concatenate the optimization of operational parameters for effective design of recycling tunnel sprayer.

Materials and Methods

Guava orchard 1.5 year old (L-49 variety) planted at ICAR-Central Institute of Agricultural Engineering Farm; Madhya Pradesh, India was selected for the present study. The length and width of the plant canopy was measured along and across the direction of travel respectively. The height of the plant was calculated by measuring the vertical difference of the lowest and top part of the canopy. The extreme points were properly marked along the periphery of the plant canopy. Same procedure was replicated for measurement of the dimensional parameters for randomly selected plants. The measured dimensional properties of the plant canopies are presented in (Table 1).

Estimation the Leaf Area

Researchers have used various methods for estimation of plant leaf area. Based on the availability of resources and expertise grid count, regression model and image processing method has been selected for estimation of the leaf area.

Grid Count Method

Various investigators have used the standard grid count method as a reference for comparison of leaf area.[12,13] Considering the accuracy of the grid count method, it was preferred as reference method in the present study. Freshly plucked leaves were collected and transferred in plastic bags from randomly selected trees of guava orchard and brought to the laboratory. This was followed by tracing the shape of every leaf on a graph paper and the leaf area was estimated by computing the no of grids of the graph part with respect to the selected scale.

Regression Model

Regression model was developed based on width, length and weight of leafs randomly collected from the test field. All the samples were collected at the same time from the field considering the moisture loss from transpiration of the leaf samples.

The width and length of freshly plucked guava leafs were measured. The width of the leaves was measured from end-to-end between the widest lobes of the lamina and length was from the tip of the leaf to end of the petiole. The method adopted was analogous to common approach followed by various researchers for the development of multiple linear regression models for different horticultural crops.[14–23]

In multiple linear regression models, several independent variables are used to model a single dependent variable.[24] The width, length and weight of the leaf were considered as independent parameters, whereas leaf area was considered as a dependent parameter. The relationship among the independent variables was analyzed by the means of least square method of the regression analysis using SAS 9.4 package program. The aim of the multiple linear regression models is to estimate the $\beta = (\beta_0, \beta_1, \beta_2 \ldots\ldots, \beta_p)$ from the data $(X_{i1}, X_{i2} \ldots\ldots, X_{ip}, Y_i)$. In this study, the model had four parameters: an intercept, b_0 and three regression coefficient, b_1, b_2 and b_3.These

Table 1 — Dimensional parameters of the trees

Tree	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Minimum height, m	0.75	0.5	0.55	0.60	0.80	0.55	0.65	0.45	0.45	0.55
Maximum height, m	1.80	1.95	1.97	1.74	2.05	1.95	1.75	1.60	1.58	1.45
Canopy range, m	1.05	1.45	1.42	1.14	1.25	1.40	1.10	1.25	1.13	0.90
width, m	1.5	1.00	1.38	1.36	1.60	1.28	1.08	1.25	1.25	1.05
length, m	1.46	1.50	1.00	1.54	1.36	1.05	0.85	1.15	1.02	0.88

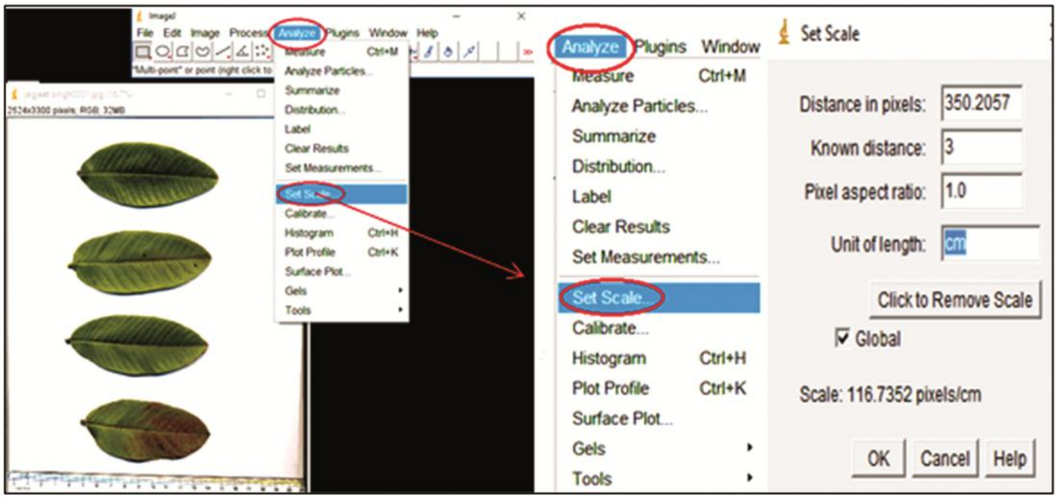

Fig. 1 — Scale setting in image j software

coefficients were used to develop regression model for the leaf area measurement as shown in equation (1).

$$Y = b_0 + b_1X_1 + X_2b_2 + X_3\,b_3 \qquad \ldots (1)$$

where, Y = dependent variable, leaf area; X = independent variables: X_1 (width), X_2 (length) and X_3 (weight) of the leaf.

Image Processing Technique

In spite of being one of the accurate methods of area estimation, grid count method is rarely used for area estimation due to its tedious and uneconomical process. At the same time, regression models are fast yet inaccurate. To overcome these issues image processing technique was used for computation of leaf area. Some studies have reported high accuracy and effectiveness of Image j software for leaf area measurement.[25,26] Hence, Image j software was chosen as an image processing technique, in order to calculate the leaf area of desired sample. Image j is an open source java based image processing program developed for optical and computational instrumentation.

The plucked leaves need to be scanned at 600 dpi or above and saved in colored bitmap or jpeg format. The saved jpeg format images were imported to image J software and was magnified using the magnifying glass tool from the tool bar. This was followed with setting scale on the magnified image (Fig. 1).

The image was converted into an 8 bit image binary image. Then the individual's leaves were

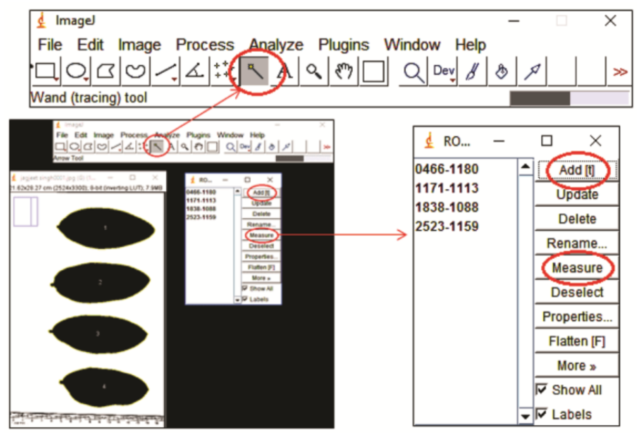

Fig. 2 — Leaf area estimation

selected to measure the leaf area (Fig. 2). The final results were obtained and saved in excel format.

Measurement of Leaf Area Density

The leaf area density refers the ratio of total leaf area in particular zone respective to volume of that zone (m^2/m^3). It represents an actual canopy volume of the tree and plays a crucial in the droplet deposition, penetration and recycling rate of spray liquid. The LAD restricts penetration and recycling rate of the spray liquid, as results of this lead to encourage the infestation at the inner side of the canopy and wastage of the pesticide. In this study, LAD was measured manually. Thus, height of every tree was classified into15 zones by keeping the constant difference between the two zones.

At least rig was developed using hollow square pipe having size of (2 × 2 × 2 m: Height × Width × Length) for the measurement of the LAD as shown in Fig. 3 (a–c), respectively.

Fig. 5 — Leaf area densities of the ten guava trees

top and bottom. This is attributed to the canopy configurations of guava trees. The observed results will help to comprehend the density of the canopy volume for the trees and could be used for the framing the strategies for spray application.

Conclusions

The study presented an insight, to measure leaf area and leaf area density for accurate estimation of the application rate, droplet density, droplet deposition and % coverage for a given plant geometry and configuration. Grid count, image processing and regression model was used for estimation of leaf area. The rapid and simple regression model was developed and used to predict the leaf area of guava leaves in the present study. This model was selected for leaf area estimation for its simplicity and produced considerable results compared to other methods like grid count and image processing.

From the study, it was concluded that length and width of leaf were found statistically significant at the level of 1%, except weight of the leaf. This study revealed that the image processing technique provided better results for leaf area estimation with mean error ± standard deviation (-0.23 ± 3.41) as compare to that of the regression model. The model validation results confirmed that regression model is accurate, simple and non-expensive tools for non-destructive leaf area estimation. The desired leaf sample has to pluck from the tree canopy for the estimation of leaf area in Image J software based image processing technique, which effect photosynthesis process of the tree, which is major drawback of opted technique in this study. This study verified the accuracy of image processing technique for the leaf area estimation, which allow the researchers to deal with voluminous of leafs. It could be used for the tunnel sprayer design purpose.

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